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TECHNICAL REPORT NO. 549

COMPUTER PROGRAMS FOR A REACTIVE TURBULENT BOUNDARY LAYER - AIR VERSION

By B. Bellow

September 15, 1965

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COMPUTER PROGRAMS FOR A REACTIVE TURBULENT BOUNDARY LAYER - AIR VERSION*

By B. Bellow

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SUMMARY

Computer programs for the calculation of properties within a reactive compressible turbulent air boundary layer on a flat plate are described. The pressure is constant throughout the boundary layer. The partial differential equations for energy and species mass conservation are solved with arbitrary initial conditions by a finite difference technique. A variable wall temperature boundary condition may be used. The boundary conditions at the edge of the boundary layer are constant with respect to the axial coordinate. The partial differential equations, which describe a two-dimensional diffusing flow may be coupled to a system of equations describing a one-dimensional finite-rate air chemically reacting flow, and hence may be used in the numerical treatment of the two-dimensional reacting boundary layer.

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COMPUTER PROGRAMS FOR A REACTIVE TURBULENT BOUNDARY LAYER - AIR VERSION

By B. Bellow

INTRODUCTION

This report describes an IBM-7094 computer program written in the FORTRAN II language to calculate properties within the turbulent boundary layer, with air chemistry. The analysis is described in Ref. 1. There are three versions of this program, reflecting the substructure, reference, and sublayer hypotheses.

Section I of this report will describe the details common to all versions. Sections II and III will outline those features peculiar to the substructure, reference, and sublayer versions. The major differences in the three versions are the computation of the parameter $d/d\chi(\ln \sigma)$ and the input format for execution on the IBM 7094.

I. TURBULENT BOUNDARY LAYER-AIR CHEMISTRY

A. Basic Equations Used

The program solves two partial differential equations for the dependent variables. stagnation enthalpy ratio, "G", and species mass fractions, "Y_k", as functions of the two independent variables χ and ψ. These equations are:

$$\frac{\partial G}{\partial \chi} = \frac{\partial}{\partial \psi}\left[\frac{\tilde{u}}{P_e}\frac{\partial G}{\partial \psi} + \frac{u_e^2}{2h_e}\left(1-\frac{1}{P_e}\right)\tilde{u}\,\frac{\partial(\bar{u})^2}{\partial \psi}\right] - \left[\psi\frac{d}{d\chi}(\ell n\ \sigma)\right]\frac{\partial G}{\partial \psi} \tag{1}$$

$$\frac{\partial Y_k}{\partial \chi} = \frac{\partial}{\partial \psi}\left[\frac{u}{S_e}\frac{\partial Y_k}{\partial \psi}\right] - \left[\psi\frac{d}{d\chi}(\ell n\ \sigma)\right]\frac{\partial Y_k}{\partial \psi} \tag{2}$$

[k = 1 to 7 in Eq. (2) referring to species $O, N, NO, O_2^-, O_2, N_2, NO^+$]

Explanation of symbols:

Constants in coefficients

P_e - Prandtl number

S_e - Schmidt number

u_e - Reference velccity

h_e - Reference enthalpy

Parameters that are dependent on χ and ψ.

$$\bar{u} = u/u_e \quad , \quad G = \frac{h}{h_e} \tag{3}$$

$$\tilde{u} = \frac{\bar{u}}{\bar{\bar{u}}_e} \left\{ \left(\frac{\bar{\bar{\epsilon}}}{\gamma} + 1 \right) \varphi \frac{d}{d\chi} (\ln \sigma) \left[g(\zeta, \chi) \right] \right\} \tag{4}$$

$$\frac{d}{d\chi} (\ln \sigma) = - \frac{1}{\mu_s} \frac{d}{d\chi} (\mu_s) \tag{5}$$

Equations (1) and (2) are converted to difference form and solved by a tri-diagonal matrix method in subroutine STEP. (See Section I-B for method of solution.) The species equation [Eq. (2)] is solved first, followed by the energy equation [Eq. (1)]. A two-dimensional grid of lattice points in the (ζ, ψ) plane is constructed as shown in Fig. 1.

The properties of these mesh are identified by suitable subscripts and superscript as described below:

Subscript, i - mesh points in ψ direction

k - scans over 7 species

Superscript, n - mesh points in ξ direction.

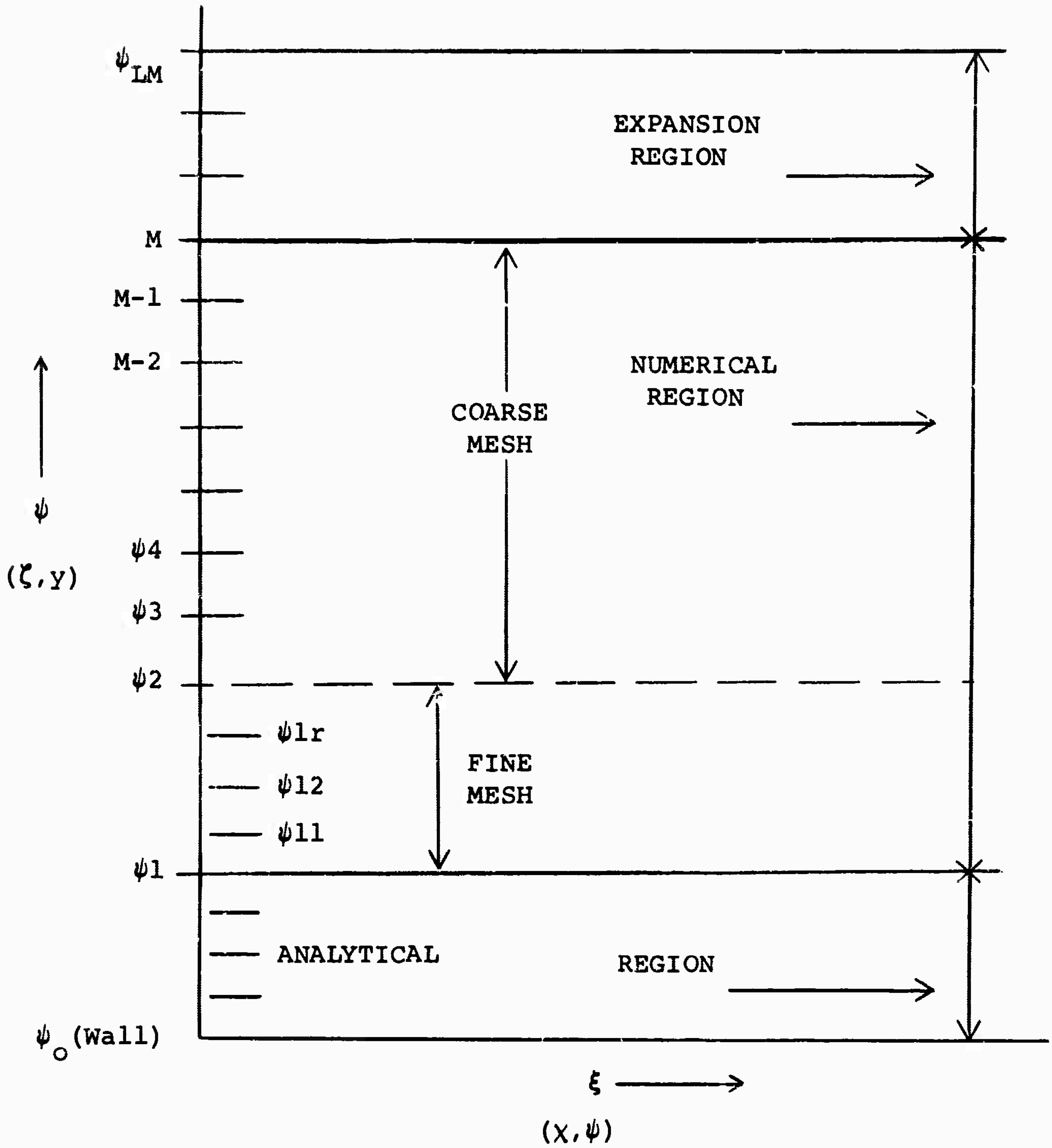

FIG. 1. LATTICE POINTS IN THE (ξ, ψ) PLANE

Subroutine STEP accepts the solutions of the difference equations from the main program at horizontal point ξ^n for all vertical points ψ_i and then steps in the ξ-direction to calculate the species, Y_k, and the enthalpy ratio, G, at point ξ^{n+1} for all ψ_i points. This data is supplied to the main program, for the subsequent calculation of the other thermodynamic properties.

The mesh in the ψ direction (see Fig. 1) is divided into several regions. From the wall at $\psi = 0$, an analytical region extends to $\psi = \psi_1$ in which species and enthalpy ratios are found from analytical expressions. For the region $\psi_1 < \psi \leq \psi_M$, the difference equations are solved using a fine mesh immediately above the analytical region and a course mesh in the remainder of the region. The fine mesh size was required to provide the necessary numerical accuracy in the solution of the equations. There is an expansion region above $\psi = \psi_M$.

1. Equations for Variables Computed in Analytical Region

$$C1 = \frac{\sqrt{2}\,\varphi}{3\Delta\,\xi} \tag{6}$$

$$GAMMA = -\frac{1}{\varphi^2}\left\{\frac{u_e^2}{h_e}\left[1-\frac{1}{P_e}\right]P_e\right\} \tag{7}$$

$$\text{BETA} = (C1)(P_e)\left\{G_o^{n+1} - G_o^n\right\} \tag{8}$$

$$\text{ALPHA} = \frac{\left[G_1^{n+1} - G_o^{n+1}\right]}{\sqrt{\psi_1}} - \sqrt{\psi_1}\ (\text{GAMMA}) \ . \tag{9}$$

The analytical region, extending from $\psi = 0$ (wall) to $\psi = \psi_1$ may be subdivided into an integral number of ψ steps. In this interval, the enthalpy ratios, G_i, and species mass fractions $(Y_k)_i$ are computed from the relations:

$$G_i^{n+1} = G_o^{n+1} + \sqrt{\psi_1}\left\{\text{ALPHA} + \frac{\text{BETA}\ (\psi_i - \psi_1)}{1.0 - \left\{\frac{d}{d\chi}(\ln\sigma)\right\} g_i} + \sqrt{\psi_1}\ \text{GAMMA}\right\} \tag{10}$$

$$\left(Y_k\right)_i^{n+1} = \left(Y_k\right)_o^{n+1} + \frac{(C1)(\psi_i)^{3/2} S_e\left\{\left(Y_k\right)_o^{n+1} - \left(Y_k\right)_o^{n}\right\}}{1.0 - \left\{\frac{d}{d\chi}(\ln\sigma)\right\} g_i} \ . \tag{11}$$

The static enthalpy, h, is found from the stagnation enthalpy and velocity by:

$$h_i = h_e G_i - \frac{1}{2}\bar{u}_i^2 u_e^2 \ . \tag{12}$$

The mixture temperature T_i is then obtained from subroutine ENTHLP which computes temperature from static enthalpy and species mass fractions (see Ref. 2).

The mixture molecular weight $(WT)_i$ and density ratio $(RH)_i$ are found from

$$(WT)_i = \frac{1.0}{\sum_k \frac{(Y_k)_i}{M_k}} \tag{13}$$

$$(RH)_i = \frac{(WT)_i}{\left(\frac{T_i}{T_e}\right) \Big/ \sum_k \frac{(Y_k)_e}{M_k}} \tag{14}$$

M_k = molecular weight of k^{th} specie

$(Y_k)_e$ = species reference mass fractions (at edge).

The quantities M_k and $(Y_k)_e$ are input data to the problem.

The g_i's in Eqs. (10) and (11) and the velocity ratios $\bar{u}_i$ are computed in subroutine HERB using the equations of Ref. 1.

The incompressible viscosity "I-VIS" is found from:

$$(I\text{-}VIS)_i = \tilde{u}_i/\bar{u}_i \; . \tag{15}$$

If the compressible viscosities "C-VIS" are computed (see Sense Switch 1 Option in Section V), they are found using the relation:

$$(\text{C-}\overline{\text{V}}\text{IS})_i = \left\{ \frac{(\text{I-VIS})_i + \left[\frac{d}{d\chi}(\ell n\ \sigma)\right] g_i}{(C/\overline{\mu})^2} \right\} \left\{ \frac{\tilde{\xi}\ \rho_o}{(\mu)_o (\mu)_i (\rho)_i} \right\} . \qquad (16)$$

The parameter $(C/\overline{\mu})$ is explained in Sections II and III.

The viscosity μ and the parameter $\tilde{\xi}$ are computed from the relations:

$$\mu_{AIR} = \frac{(3.05 \cdot 10^{-8})\, T^{3/2}}{T + 111.0} \ ; \ T \text{ in deg. Kelvin} \qquad (17)$$

$$\tilde{\xi} = \frac{\left(\frac{\mu_o}{\mu_s}\right)^2}{1.0 - \varphi^3 \theta \frac{d}{d\chi} (\ell n\ \sigma)} \qquad (18)$$

where φ and θ are functions computed in subroutine HERB (see Ref. 1), and the subscript s which is explained later in Section I I A refers to edge of the sublayer.

2. Difference Equations Used for Numerical Solutions

(a) Generic Form of Difference Equations

The form of the generalized difference equation used to compute species concentrations and energy in the region, $\psi_1 < \psi \leq \psi_M$, is presented in part B of this section and is of the form

$$a\, P_{i-1} + b\, P_i + c\, P_{i+1} = d \tag{19}$$

The coefficients of these equations are computed and then the resulting set of linear simultaneous equations are solved in subroutine STEP, first for species and then for the enthalpy ratio. The incompressible eddy viscosities, $\tilde{u}_i$, are supplied to STEP by subroutine HERB. These viscosities are then corrected at each ψ point for compressibility:

$$\tilde{u}_{COMP} = \tilde{u}_{INCOMP} - \bar{u}\left[\frac{d}{d\chi}(\ell n\ \sigma)\right](g) \tag{20}$$

where $\bar{u}_i$ and g_i are also obtained from HERB. These compressible $\tilde{u}$'s are used in the computation of the a, b, c coefficients in the generic difference Eq. (19) and will be referred to as $\tilde{u}$ with no subscript. For the species conservation equation, the P_i in the difference equation (19) represents $(Y_k)_i$ and the coefficients are:

$$\lambda_Y = \frac{S_e(\Delta\,\psi)^2}{\Delta\,\chi} \tag{21}$$

$$a_i = \tilde{u}^{n+1}_{i-\frac{1}{2}} + S_e(\Delta\,\psi)\,(\psi)_i\,\frac{d}{d\chi}\,(\ell n\;\sigma) \tag{22}$$

$$b_i = -\left[\lambda_Y + \tilde{u}^{n+1}_{i+\frac{1}{2}} + \tilde{u}^{n+1}_{i-\frac{1}{2}}\right] \tag{23}$$

$$c_i = \tilde{u}^{n+1}_{i+\frac{1}{2}} - S_e(\Delta\,\psi)\,(\psi)_i\,\frac{d}{d\chi}\,(\ell n\;\sigma) \tag{24}$$

$$(d_k)_i = -\,\lambda_Y(Y_k)^n_i \tag{25}$$

In the fine mesh region (Fig. 1) the above relations are used from i = 11 to i = 1r with $\Delta\,\psi$ being the fine ψ-interval. ψ_{11} is the first fine mesh point above ψ_1 and ψ_{1r} is the last fine mesh point below ψ_2.

In the coarse mesh region, the above relations are used from i = 3 to i = M with $(\Delta\,\psi)_c$ being the coarse ψ interval.

For ψ_2,

$$\lambda_{Y_2} = \frac{S_e (\Delta \psi)^2_c}{2\Delta \chi} \left| 1.C + \frac{1.0}{B} \right| \qquad (26)$$

B is the total number of fine mesh intervals. Equations (22)-(25) become:

$$a_2 = B \tilde{u}^{n+1}_{2-\frac{1}{2}} + \frac{S_e}{2} (\Delta \psi)_c \psi_2 \frac{d}{d\chi} (\ell n\ \sigma) \qquad (27)$$

$$b_2 = - \left[\lambda_{Y_2} + \tilde{u}^{n+1}_{2+\frac{1}{2}} + B \tilde{u}^{n+1}_{2+\frac{1}{2}} \right] \qquad (28)$$

$$c_2 = \tilde{u}^{n+1}_{2+\frac{1}{2}} - \frac{S_e}{2} (\Delta \psi)_c \psi_2 \frac{d}{d\chi} (\ell n\ \sigma) \qquad (29)$$

$$(d_k)_2 = - \lambda_{Y_2} (Y_k)^n_2 \qquad (30)$$

For the generic form of the enthalpy ratio difference equations, relations (21)-(24) and (26)-(29) are used with the Schmidt number "S_e" replaced by the Prandtl number "P_e."

Relation (25) for the right-hand side of (19) is replaced by:

$$d_i = -\left[\lambda_e (G)_i^n + (R)_i - (R)_{i-1}\right] \tag{31}$$

where

$$R_i = \left[P_\epsilon \frac{u_e^2}{2h_e} \left(1 - \frac{1}{P_e}\right)\right] \tilde{u}_{i+\frac{1}{2}} \left[\overline{u}^2_{i+2} - \overline{u}^2_{i+1}\right] \tag{32}$$

which is an approximation to the term involving $\frac{\partial}{\partial \psi}\left[\frac{u_e^2}{2h_e}\left(1 - \frac{1}{P_e}\right) \tilde{u} \frac{\partial (\overline{u})^2}{\partial \psi}\right]$ in the energy equation (1). For the λ_e in Eq. (31)

$$\lambda_e = \frac{P_e (\Delta \psi)^2}{\Delta \chi} \tag{33}$$

where the appropriate $\Delta\psi$ is used depending on coarse or fine mesh region. For i = 2 Eq. (31) is used for d_2 with λ_e replaced by

$$\lambda_{e2} = \frac{P_e (\Delta \psi)_c^2}{2(\Delta \chi)} \left(1.0 + \frac{1.0}{B}\right) \tag{34}$$

B is the number of fine mesh intervals.

(b) <u>Boundary Conditions for Difference Equations at $\psi = \psi_1$</u>

At $\psi = \psi_1$ the generic forms of the species and energy equations are replaced by special analytical relations. For the species equation, these are:

$$a_{1s} = 0 \tag{35}$$

$$b_{1s} = \frac{\psi_1 + (\Delta\psi)_F}{2\,(\Delta\xi)} + \frac{\tilde{u}_{3/2}}{(\Delta\psi)_F\, S_e} + \frac{1}{A}\left\{\frac{\psi_1}{2(\Delta\xi)} + \left[\frac{\psi_1 + (\Delta\psi)_F}{2}\right]\left[\frac{d}{d\chi}\,(\ln\sigma)\right]\left[1.5(A-1)\right]\right\} \tag{36}$$

$$c_{1s} = -\frac{\tilde{u}^{n+1}_{3/2}}{S_e(\Delta\psi)_F} \tag{37}$$

$$(d_k)_{1s} = \left[\frac{\psi_1 + (\Delta\psi)_F}{2\,(\Delta\xi)}\right](Y_k)^n_1 + \left[\frac{\psi_1 + (\Delta\psi)_F}{2}\right]\left[A-1.0\right](Y_k)^n_o + \frac{1}{A}\left\{\frac{3\left[1-\frac{d}{d\chi}\,(\ln\sigma)\cdot g_1\right]}{S_e\sqrt{2\psi_1}\;\varphi[\psi_1 + (\Delta\psi)_F]}\right\} \tag{38}$$

where $(\Delta \psi)_F$ is the fine mesh interval and

$$A = 1.0 + \frac{S_e \sqrt{2}\, \varphi(\psi_1)^{3/2}}{[3(\Delta \xi)] \left[1.0 - \frac{d}{d\chi} (\ln \sigma) \cdot g_1\right]} \tag{39}$$

After solution of the species equations for the range of ψ from ψ_1 to ψ_M, the species values at the wall are calculated using the following relation:

$$(Y_o^{n+1})_k = \frac{1}{A} \left[Y_1^{n+1} + (A-1.0) Y_{wall}^n\right]_k \tag{40}$$

The wall enthalpy ratio is found by subroutine ENTHLP from the wall mass fractions $(Y_o^{n+1})_k$ and the wall temperature.

The energy equation is then solved for the values, G_i, with the following boundary conditions at $\psi = \psi_1$:

$$a_{1e} = 0 \tag{41}$$

$$b_{1e} = \frac{\psi_1 + (\Delta\psi)_F}{2(\Delta\xi)} + \frac{\tilde{u}^{n+1}_{3/2}}{(\Delta\psi)_F P_e} + \frac{\left(1 - \frac{d}{d\chi}(\ln\sigma)\cdot g_1\right)}{P_e\sqrt{2\psi_1}\ \varphi}$$

$$+ \left[\frac{d}{d\chi}(\ln\sigma)\right]\left[\frac{\psi_1 + (\Delta\psi)_F}{4\sqrt{2}}\right] \tag{42}$$

$$c_{1e} = -\frac{\tilde{u}^{n+1}_{3/2}}{P_e(\Delta\psi)_F} \tag{43}$$

$$d_{1e} = \left[\frac{\psi_1 + (\Delta\psi)_F}{2(\Delta\xi)}\right] G_1^n + \left[\frac{-\psi_1}{6(\Delta\xi)} + \frac{1 - \left(\frac{d}{d\chi}(\ln\sigma)\cdot g_1\right)}{P_e\sqrt{2\psi_1}\ \varphi}\right] G_o^{n+1}$$

$$+ \left[\frac{\psi_1}{6(\Delta\xi)}\right] G_o^n$$

$$+ \frac{1}{2}\frac{u_e^2}{h_e}\left[1 - \frac{1}{P_e}\right]\frac{\tilde{u}^{n+1}_{3/2}}{(\Delta\psi)_F}\left[\bar{u}_2^2 - \left(\frac{\sqrt{2\psi_1}}{\varphi}\right)^2 - \frac{\sqrt{2\psi_1}}{\varphi^2}\left(1 - \frac{d}{d\chi}(\ln\sigma)\cdot g_1\right)\right]$$

$$- \left[\frac{d}{d\chi}(\ln\sigma)\right]\left[\frac{\psi_1 + (\Delta\psi)_F}{2}\right]\left\{-\frac{G_o^{n+1}}{2\sqrt{2}} - \frac{\left(1 - \frac{1}{\sqrt{2}}\right)u_e^2\left(1 - \frac{1}{P_e}\right)2P_e(\psi_1)^{3/2}}{(2h_e)\ 6(\Delta\xi)\left(1 - \frac{d}{d\chi}(\ln\sigma)\cdot g_1\right)}\right.$$

$$\left. + \left[\frac{\sqrt{2}\ \varphi(\psi_1)^{3/2}\ P_e}{6(\Delta\xi)\left(1 - \frac{d}{d\chi}(\ln\sigma)\cdot g_1\right)}\right]\left[G_o^{n+1} - G_o^n\right]\right\}. \tag{44}$$

3. Treatment of Psi Expansion Region

To ensure that the solutions satisfy the boundary conditions at the edge, an expansion region is included in the ψ direction.

Before solution of the species equations at the current step, those solutions obtained at $\psi = \psi_{LM}$ for the previous step, are compared with $(Y_k)_e$, which are input. If these comparisons differ by more than a specified tolerance, called EPS, for any one of the species, the values $(Y_k)_e$. are prescribed at an additional ψ point which is added to the mesh (LM is increased by one). The convergence test is:

$$\text{Is } \left| \frac{(Y_k)_{LM} - (Y_k)_e}{(Y_k)_e} \right| \leq \text{EPS ?} \qquad (45)$$

NO - add 1 point to mesh

YES - do not add a point to mesh.

A similar test is performed on the energy equation solution. The test is as follows:

$$\text{Is } \left| G_{LM} - 1.0 \right| \leq \text{EPS ?} \qquad (46)$$

NO - add 1 point to mesh

YES - do not add a point to mesh.

At all points in the expansion region, the $\tilde{u}$ and $\bar{u}$ viscosity parameters are set equal to the values of $\tilde{u}$ and $\bar{u}$ at $\psi = \psi_M$. The compressibility correction on $\tilde{u}$ is not applied in this region.

4. Equations for Parameters Computed after Solution of Difference Equations

Upon obtaining the solutions to the species and energy equations in the numerical region, the main program computes mixture temperature ratios, T_i/T_e, molecular weights, $(WT)_i$, density ratios, $(RH)_i$, and incompressible viscosities, $(I\text{-}VIS)_i$, using Eqs. (12) through (15). If desired, compressible viscosities are obtained, using (16). These parameters are printed as output.

The program then computes a value of $\frac{d}{d\chi}(\ln \sigma)$ to be used for the next step in the χ direction. The methods used distinguish the substructure, reference, and sublayer versions and will be detailed in Sections II and III.

Having obtained $\frac{d}{dX}(\ln \sigma)$, the physical coordinate "X" may be found from the coordinate χ using

$$X - X_{in.} = \frac{\mu_o}{\rho_o u_e} \int_{\chi_{in.}}^{\chi} \frac{1 - \varphi^3 \tilde{\theta} \left(\frac{d}{dX} (\ln \sigma) \right)}{\left(\frac{\sigma}{\bar{\mu}} \mu_o \right)^2} d\tilde{\chi} \qquad (47)$$

where $X_{in.}$ is the initial value of X, and $\chi_{in.}$ is the corresponding value of χ.

Other quantities computed and printed are the heat transfer "Q-DOT," and the skin friction coefficient CF, which are defined by the following relationships:

$$\dot{q} = - \frac{.001285\ \mu_o \left(\frac{\sigma}{\mu}\right) \rho_o u_e h_e \alpha}{\sqrt{2}\ \varphi\ P_e} \tag{48}$$

$$CF = \frac{2.0\ \mu_o \left(\frac{\sigma}{\mu}\right) T_e}{\varphi^2\ T_o} \tag{49}$$

The units of $\dot{q}$ are $\frac{BTU}{ft^2\text{-sec}}$.

Electron mass fractions are computed from the mass fractions of O_2^- and NO^+ using the following relation:

$$Y_{e^-} = \left[\frac{Y_{NO^+}}{M_{NO^+}} - \frac{Y_{O_2^-}}{M_{O_2^-}}\right] \Big/ 1820 \ . \tag{49a}$$

The electron density in particles per cubic centimeter is computed from:

$$\text{ELECTRON PARTICLE DENSITY} = (5.67\text{x}10^{26})(\rho_{e^-})(Y_{e^-}) \tag{49b}$$

where ρ_{e} - is the density in slugs/ft^3.

5. Finite Rate Chemistry Option

An option has been provided in the program whereby one-dimensional finite rate chemistry reactions are computed using the technique of G. Moretti (Refs. 3 and 4). Using this option, the terms containing the species mass fractions are modified to reflect the coupling of the one-dimensional finite-rate chemistry relations, with the two-dimensional diffusion equations. However, since the correct time step for the chemistry equations is not known until the diffusion equations are solved, a time step iteration is required.

The iteration procedure is as follows:

(1) An approximate Δ X is computed from the previous temperature and species profiles:

$$(\Delta X)^{(1)} = \left[\frac{\mu_o}{\rho_o \mu_e}\right] \left[\frac{1-\varphi^3 \tilde{\theta} \left[\frac{d}{dX} (\ln \sigma)\right]}{\left(\frac{\sigma}{\bar{\mu}} \mu_o\right)^2}\right] (\Delta X) \qquad (50)$$

$$(\Delta t)_i^{(1)} = \frac{(\Delta X)^{(1)}}{(\rho_e u_e / \mu_e) \bar{u}_i} \quad . \qquad (51)$$

(2) A finite rate chemistry step is performed at each mesh point, ψ_i, on the species mass fractions, using the corresponding temperature and density profiles and the "Δ t" profile computed from Eq. (51).

(3) The diffusion equations are then solved using the chemically modified species profiles.

(4) New values of $\frac{d}{d\chi}$ ($\ell n\ \sigma$) and $c/\bar{\mu}$ are computed, and then $(\Delta X)^{(2)}$ found, using (50).

(5) $(\Delta X)^{(2)}$ is compared to $(\Delta X)^{(1)}$. If they are within the specified tolerance, the species and energy solutions are printed as the correct solutions. If the tolerance is not met, steps 2-5 are repeated with the new value of (Δ t). Note that in this case the new value of $\frac{d}{d\chi}$ ($\ell n\ \sigma$) from step (4) is not used in the left side matrices of the diffusion equations for the next iteration. It is only used to get a new (Δ t) approximation for the chemistry calculation.

B. Numerical Methods of Solution of Basic Equations

Partial differential Eqs. (1) and (2) are solved by an implicit second-order central difference method known as the Crank-Nicolson Difference Equation.

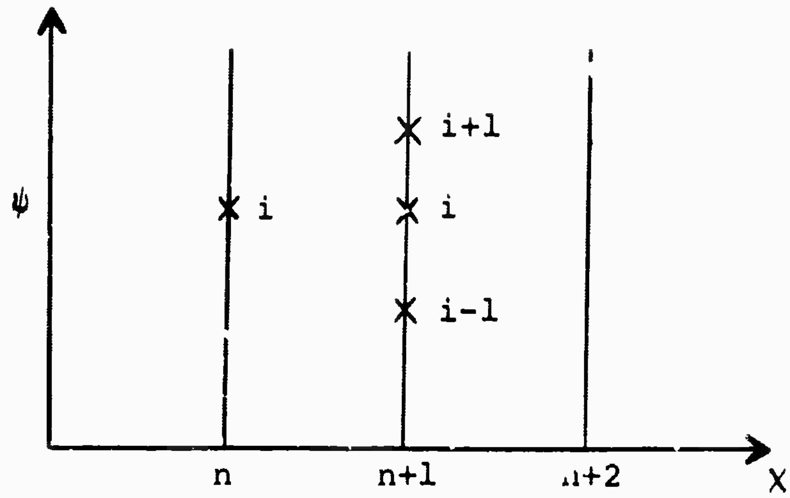

FIG. 2. CRANK-NICOLSON LATTICE POINTS

Assuming a two-dimensional mesh of lattice points with "n" representing the horizontal or χ direction and "i" representing the vertical, or ψ direction, we solve the equation,

$$\frac{\partial P}{\partial \chi} = \frac{\partial}{\partial \psi}\left[\tilde{u}(\chi,\psi)\ \frac{\partial P}{\partial \psi}\right] \tag{52}$$

at a point (n+1), i, assuming known values of P at point n for all values of i. Replace the right side of (52) by a linear relation for the derivative $\frac{\partial[\ ]}{\partial \psi}$ from $i-\frac{1}{2}$ to $i+\frac{1}{2}$:

$$\frac{\partial P}{\partial X} = \frac{\left(\tilde{u}\,\frac{\partial P}{\partial \psi}\right)^{n+1}_{i+\frac{1}{2}} - \left(\tilde{u}\,\frac{\partial P}{\partial \psi}\right)^{n+1}_{i-\frac{1}{2}}}{\Delta\,\psi_i} \quad . \tag{53}$$

Each term in the numerator of (53) is approximated in the same manner.

$$\left(\tilde{u}\,\frac{\partial P}{\partial \psi}\right)^{n+1}_{i+\frac{1}{2}} = \tilde{u}^{n+1}_{i+\frac{1}{2}} \left[\frac{P_{i+1}-P_i}{\Delta\,\psi_i}\right]^{n+1} \tag{54}$$

$$\left(\tilde{u}\,\frac{\partial P}{\partial \psi}\right)^{n+1}_{i-\frac{1}{2}} = \tilde{u}^{n+1}_{i-\frac{1}{2}} \left[\frac{P_{i}-P_{i-1}}{\Delta\,\psi_i}\right]^{n+1} \quad . \tag{55}$$

The left side of (2) is

$$\frac{\partial P}{\partial X} = \frac{P^{n+1}_i - P^n_i}{\Delta\,X} \quad . \tag{56}$$

Inserting (54)-(56) into (53)

$$\frac{P^{n+1}_i - P^n_i}{\Delta\,X} = \frac{1}{(\Delta\,\psi)^2_i}\left[\tilde{u}_{i+\frac{1}{2}}\,(P_{i+1}-P_i) - \tilde{u}_{i-\frac{1}{2}}(P_i-P_{i-1})\right]^{n+1} . \tag{57}$$

Multiplying both sides of (57) by $(\Delta\,\psi^2)$ and rearranging terms, the difference equation becomes:

$$\tilde{u}_{i-\frac{1}{2}}\, P_{i-1}^{n+1} - \left[\frac{(\Delta\,\psi)_i^2}{\Delta\,\chi} + \tilde{u}_{i+\frac{1}{2}} + \tilde{u}_{i-\frac{1}{2}}\right] P_i^{n+1} + \tilde{u}_{i+\frac{1}{2}}\, P_{i+1}^{n+1} = -\frac{(\Delta\,\psi)_i^2}{\Delta\,\chi}\, P_i^n \;. \tag{58}$$

Let

$$a_i = \tilde{u}_{i-\frac{1}{2}}$$

$$b_i = -\left[\frac{(\Delta\,\psi)_i^2}{\Delta\,\chi} + \tilde{u}_{i+\frac{1}{2}} + \tilde{u}_{i-\frac{1}{2}}\right]$$

$$c_i = \tilde{u}_{i+\frac{1}{2}}$$

$$d_i = -\frac{(\Delta\,\psi)_i^2}{\Delta\,\chi}\, P_i^n \;.$$

Then (58) may be written in the form,

$$a_i P_{i-1}^{n+1} + b_i P_i^{n+1} + c_i P_{i+1}^{n+1} = d_i \;. \tag{59}$$

Since all P_i for a particular mesh line, n+1, are solved simultaneously for i=1 to ℓ, then we have a set of ℓ equations of type (59) for the unknown P_i's.

written in matrix form as

$$\begin{bmatrix} b_1 & c_1 & 0 & 0 & 0 & 0 & 0 \\ a_2 & b_2 & c_2 & 0 & 0 & 0 & 0 \\ 0 & a_3 & b_3 & c_3 & 0 & 0 & 0 \\ . & . & . & . & . & . & . \\ 0 & 0 & 0 & 0 & 0 & a_\ell & b_\ell \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ . \\ P_\ell \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ . \\ d_\ell \end{bmatrix} \tag{61}$$

or

$$AP = D \tag{62}$$

To solve for the unknown P's, the coefficient matrix (called A) is factored into a product of two matrices as follows:

$$[M\ N]\ P = D \tag{63}$$

where

$$M = \begin{bmatrix} \beta_1 & 0 & 0 & 0 & 0 \\ \alpha_2 & \beta_2 & 0 & 0 & 0 \\ 0 & \alpha_3 & \beta_3 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ & & & \alpha_\ell & \beta_\ell \end{bmatrix} \tag{64}$$

$$N = \left[\begin{array}{cccccc} 1 & \gamma_1 & 0 & 0 & 0 & \cdot \\ 0 & 1 & \gamma_2 & 0 & 0 & \cdot \\ 0 & 0 & 1 & \gamma_3 & 0 & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ & & & & 1 & \gamma_{\ell-1} \\ & & & & & 1 \end{array}\right] \begin{array}{c} \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \\ \\ \end{array} \tag{65}$$

The α, β, and γ values of M and N can be evaluated by multiplying M and N and setting the elements of this product matrix equal to the corresponding elements of A. When this is done it is found that

$$\left.\begin{aligned} \alpha_i &= a_i \\ \beta_i &= b_i - \left[\frac{c_{i-1}}{\beta_{i-1}}\right] a_i \\ \gamma_i &= \frac{c_i}{\beta_i} \end{aligned}\right\} \quad i=2,\ell \tag{66}$$

and $\alpha_1 = a_1 = 0$, $\beta_1 = b_1$, $\gamma_1 = c_1/b_1$.

In (63) let $Y = NP$. Then since M is a bi-diagonal matrix the transformed unknown column matrix Y can be solved recursively from $j=1$ to ℓ, as follows:

$$\begin{bmatrix} \beta_1 & 0 & 0 & 0 & 0 \\ \alpha_2 & \beta_2 & 0 & 0 & 0 \\ 0 & \alpha_3 & \beta_3 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ & & & \alpha_\ell & \beta_\ell \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \cdot \\ \cdot \\ y_\ell \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ \cdot \\ \cdot \\ d_\ell \end{bmatrix}$$

$$
\begin{aligned}
y_1 &= d_1/\beta_1 \\
y_2 &= (d_2-\alpha_2 y_1)/\beta_2 \\
y_\ell &= (d_\ell-\alpha_\ell y_{\ell-1})/\beta_\ell \quad .
\end{aligned}
\tag{67}
$$

At this point, a boundary condition is imposed and y_ℓ is modified such that

$$
(y_\ell)' = \frac{y_\ell}{1+\dfrac{c_\ell}{\beta_\ell}}
\tag{68}
$$

where $c_\ell \equiv \tilde{u}_e$.

The solutions P_i may now be calculated from y_i by sweeping backward from ℓ to 1

$$
\begin{bmatrix}
1 & \gamma_1 & 0 & 0 & 0 & \\
0 & 1 & \gamma_2 & 0 & 0 & \\
\cdot & \cdot & \cdot & \cdot & \cdot & \\
\cdot & \cdot & \cdot & \cdot & \cdot & \\
0 & 0 & 0 & 0 & 1 & \gamma_{\ell-1} \\
0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
P_1 \\ P_2 \\ \cdot \\ \cdot \\ \cdot \\ P_\ell
\end{bmatrix}
=
\begin{bmatrix}
y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_\ell'
\end{bmatrix}
\tag{69}
$$

$$P_\ell = y'_\ell$$

$$P_i = y_i - \gamma_i P_{i+1}, \quad i=\ell-1, \ell-2, \ldots 1.$$

II. SUBSTRUCTURE AND REFERENCE HYPOTHESES

A. Calculation of $d/d\chi(\ln \sigma)$

Integrals are computed over the variable "ZETA" (which is a transformed ψ coordinate) for temperature T, species Y_k, and normal coordinate "YCORD." These integrals are:

$$T_s = \frac{1}{430} \int_0^{430} T_z \, d\zeta \tag{70}$$

$$(Y_k)_s = \frac{1}{430} \int_0^{430} (Y_k)_\zeta \, d\zeta \tag{71}$$

where subscript s denotes some mean value across the layer.

As proposed by Coles, the substructure hypothesis is

$$\frac{\sigma}{\bar{\mu}} = \frac{1}{\mu_s} \tag{72}$$

where μ_s is the mean value of viscosity in the region $0 \le \zeta \le 430$ and $\bar{\mu}$ is the incompressible viscosity independent of the variable χ.

The normal y-coordinate is obtained using:

$$\text{YCORD} = \frac{\varphi}{\left(\frac{\sigma}{\bar{\mu}}\right) \rho_e \mu_e} \int_0^z \left(\frac{\rho_e}{\rho}\right) d\tilde{z} . \qquad (73)$$

The computing scheme is then as follows: The finite difference equations have been solved for the properties at χ^{n+1} using the value of $\frac{d}{d\chi}(\ell n\ \sigma)$ at χ^n (see Section I, B). (For the first step, $\frac{d}{d\chi}(\ell n\ \sigma)$ is an input value to the program.) Having now the value of μ_s^{n+1} from Eq. (17), the value $\frac{d}{d\chi}(\ell n\ \sigma)$ to be used for the step χ^{n+1} to χ^{n+2} is:

$$\frac{d}{d\chi}(\ell n\ \sigma) = -\frac{1}{\mu_s^n}\left[\frac{\mu_s^{n+1}-\mu_s^n}{\chi^{n+1}-\chi^n}\right] . \qquad (74)$$

The value of μ_s for n = 0 is computed from Eq. (17) using the input temperature and species profiles.

$\frac{d}{d\chi}(\ell n\ \sigma)$ thus lags the remainder of the solution by one step.

Referring to Fig. 1 of Section I, the fine mesh region for the substructure hypothesis extends over the interval (ψ_1, ψ_2). The ψ step size between ψ_1 and ψ_2 is therefore

$$(\Delta\,\psi)_F = \frac{\psi_2 - \psi_1}{K} \tag{75}$$

where K is an input number to the program.

The integrals over the logarithmic region [Eqs. (70) and (71)] are found by trapezoidal quadrature in subroutine INTEG, over the values of ζ used in the finite difference mesh. Temperature and species values for the upper limit ζ = 430 are found by linear interpolation.

Since the definition of ζ changes at ζ = 10.6 (see Appendix III, Ref. 1), a special approximation scheme was used for the ζ interval bracketing 10.6. This interval was split into two intervals namely, ζ_1 to 10.6, and 10.6 to ζ_2, where ζ_1 and ζ_2 are the mesh values of ζ that bracket ζ = 10.6 (see Fig. 3).

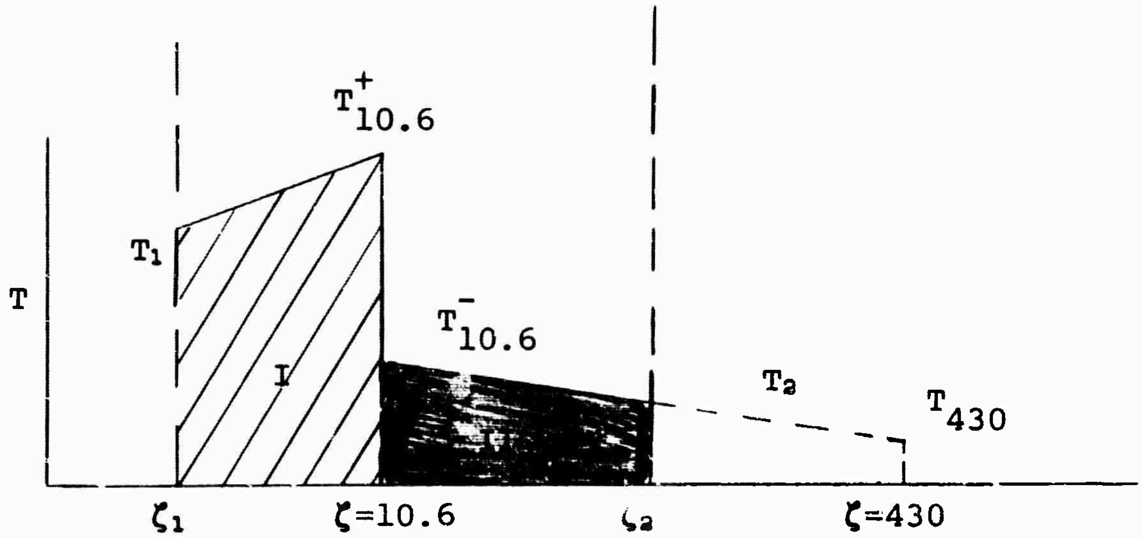

FIG. 3. QUADRATURE DIAGRAM AT ζ = 10.6

A step drop in temperature is imposed at $\zeta = 10.6$, yielding two temperature values, denoted $T^{+}_{10.6}$ and $T^{-}_{10.6}$. Two trapezoidal integrations are then performed, the first from T_1 to $T^{+}_{10.6}$, the second from $T^{-}_{10.6}$ to T_2. (See shaded areas I and II in Fig. 3.)

The values of $T^{+}_{10.6}$ and $T^{-}_{10.6}$ are obtained as follows:

$$T^{+}_{10.6} = A + B\,\beta + C\,\beta^2 \tag{76}$$

where

$$\beta = \varphi/10.6 \tag{77}$$

$$A = T_o \tag{78}$$

$$C = \frac{\left[\dfrac{T_1}{\bar{u}_1} - \dfrac{T_2}{\bar{u}_2} + T_o\left\{\dfrac{1}{\bar{u}_2} - \dfrac{1}{\bar{u}_1}\right\}\right]}{\bar{u}_1 - \bar{u}_2} \tag{79}$$

$$B = \frac{T_2 - T_o}{\bar{u}_2} - C\,\bar{u}_2\ . \tag{80}$$

The value of $T^{-}_{10.6}$ is found from a backward linear extrapolation of the temperatures T_2 and T_{430}, where T_{430} is the temperature previously found by interpolation at $\zeta = 430$.

B. Modification of Grid Mesh in Normal Direction

The number of grid mesh points in the normal or ψ direction is determined by the value of ψ_M, or upper limit of ψ in the numerical region (see Section I). The initial value of ψ_M is known and a ψ spacing of ψ_M/N is input as $(\Delta\psi)_C$. As calculation proceeds in χ direction, ψ_M increases and additional mesh points are added with the $(\Delta\psi)_C$. When the total number of these points reaches 2N, the program automatically doubles $(\Delta\psi)_C$ and halves the number of points, keeping solution values at every alternate point of the original $\Delta\psi$.

For the fine mesh region, whose interval is also doubled, alternate points are kept for the lower half of the region. Points for the upper half of the new fine mesh region are linearly interpolated (see Fig. 4).

For the coarse mesh region, every other point of the original mesh is retained.

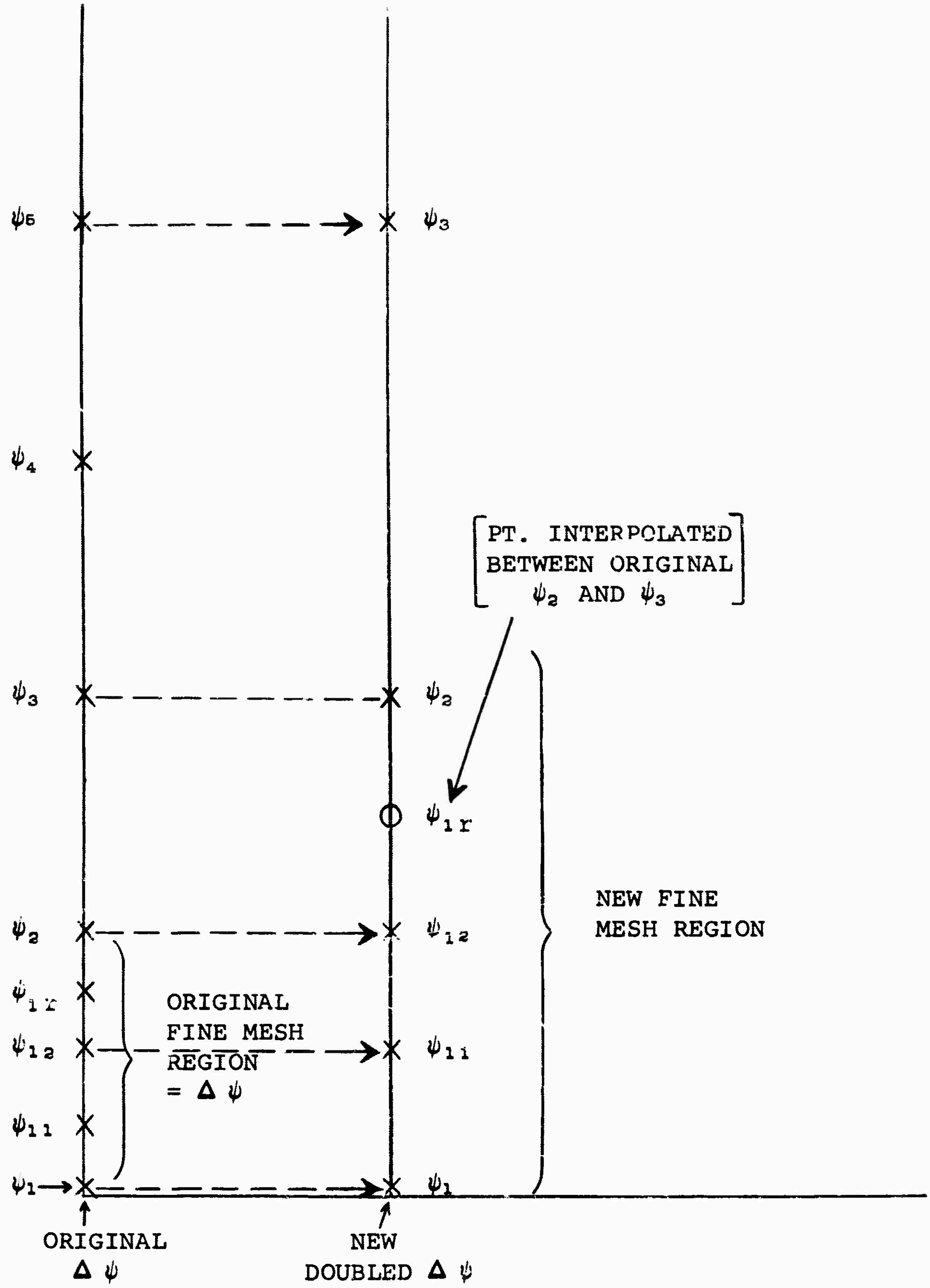

FIG. 4. DOUBLING OF $\Delta\,\psi$ GRID FOR SUBSTRUCTURE HYPOTHESIS

C. Treatment of Wall Chemical Reactions

Finite rate chemistry reactions are computed at all ψ points except at the wall, where an equilibrium chemistry computation is performed.

D. Reference Method Option

When the reference method option is exercised, $\frac{d}{dX}(\ln \sigma)$ is set equal to zero. The reference state is still given by the mean substructure values, i.e., T_s, $(Y_k)_s$, μ_s, $\sigma/\bar{\mu}$, and YCORD using relations (70), (71), (17), (72), and (73) respectively.

III. SUBLAYER HYPOTHESIS

A. Calculation of $d/d\chi(\ln \sigma)$

The sublayer assumption, proposed by Baronti and Libby, asserts that the Reynolds number based on the height of the laminar sublayer is an invariant of the compressibility transformation. Instead of relation (72) for $\sigma/\bar{\mu}$, one uses the following:

$$\frac{\sigma}{\bar{\mu}} = \frac{1}{10.6} \int_0^{56.18} \frac{\rho_s}{\rho} \frac{d\tilde{\psi}}{\sqrt{2\tilde{\psi}}} \tag{81}$$

and

$$\frac{d}{d\chi}(\ln \sigma) = \frac{\dfrac{\mu_s}{10.6} \displaystyle\int_0^{56.18} \frac{d}{d\chi}\left(\frac{\rho_s}{\rho}\right) \frac{d\tilde{\psi}}{\sqrt{2\tilde{\psi}}} - \frac{d}{d\chi}(\mu_s) \frac{1}{10.6} \displaystyle\int_0^{56.18} \frac{\rho_s}{\rho} \frac{d\tilde{\psi}}{\sqrt{2\tilde{\psi}}}}{\mu_s} \tag{82}$$

where

$$\frac{d}{d\chi}\left(\frac{\rho_s}{\rho}\right) = \frac{\rho_s}{\rho_e}\left[\frac{d}{d\chi}\left(\frac{\rho_e}{\rho}\right) - \frac{\rho_s}{\rho} \frac{d}{d\chi}\left(\frac{\rho_e}{\rho_s}\right)\right] \tag{83}$$

$$\frac{d}{d\chi}\left(\frac{\rho_e}{\rho}\right) = \frac{\partial}{\partial T}\left(\frac{\rho_e}{\rho}\right) \frac{dT}{d\chi} + \sum_k \frac{\partial}{\partial Y_k}\left(\frac{\rho_e}{\rho}\right) \frac{dY_k}{d\chi} \tag{84}$$

$$\frac{d}{d\chi}\left(\frac{\rho_e}{\rho_s}\right) = \frac{\partial}{\partial T}\left(\frac{\rho_e}{\rho_s}\right) \frac{dT}{d\chi} + \sum_k \frac{\partial}{\partial Y_k}\left(\frac{\rho_e}{\rho_s}\right) \frac{dY_k}{d\chi} \tag{85}$$

$$\frac{\partial}{\partial T}\left(\frac{\rho_e}{\rho_s}\right) = \frac{1}{T_s} \frac{\sum_k (Y_k/M_k)_s}{\sum_k (Y_k/M_k)_e} \tag{86}$$

$$\frac{\partial}{\partial Y_k}\left(\frac{\rho_e}{\rho_s}\right) = \frac{T_s}{T_e} \frac{1}{(M_k)_s} \frac{1}{\sum_k (Y_k/M_k)_s} \tag{87}$$

$$\frac{d}{d\chi}(\mu_s) = \left(\frac{d\mu_s}{dT}\right)\left(\frac{dT}{d\chi}\right) \tag{88}$$

$$\frac{d\mu_s}{dT} = \left(\frac{3.05\text{x}10^{-8}\,T}{T + 111.0}\right)\left(1.5 - \frac{T}{T + 111.0}\right) . \tag{89}$$

The derivatives $dT/d\chi$ and $dY_k/d\chi$ are evaluated numerically as:

$$\frac{dT}{d\chi} = \frac{(T)^{n+1} - (T)^n}{\chi^{n+1} - \chi^n} \tag{90}$$

$$\frac{dY_k}{d\chi} = \left[\frac{(Y_k)^{n+1} - (Y_k)^n}{\chi^{n+1} - \chi^n}\right]_i . \tag{91}$$

In relations (81) to (91), the subscript s refers to parameters evaluated at $\psi = 56.18$.

The sublayer hypothesis applies to the fine and coarse mesh ψ regions, just as the substructure hypothesis does. However, the fine mesh region now extends from ψ_1 to ψ = 56.18 and can be divided into a prescribed number of intervals.

The normal y-coordinate is still computed from relation (73). As in the substructure hypothesis, calculation of $d/d\chi(\ln \sigma)$ lags the remainder of the solution by one step.

B. Modification of Grid Mesh in Normal Direction

When the criterion for halving the number of intervals in the ψ direction is met (see paragraph 1, Section II, B), the fine mesh ψ points of the original solutions are retained, i.e. the fine mesh region is undisturbed for $0 \leq \psi \leq 56.18$ ($\psi_s = 56.18$).

For the coarse ψ mesh region, $56.18 < \psi \leq \psi_e$, every other mesh point of the original solution is retained.

C. Treatment of Wall Chemical Reactions

Finite rate chemistry reactions are computed at all ψ points. At the wall, a time step is used that is equal to the time step computed at the ψ value closest to the wall. See Eq. (51) for definition of time step $(\Delta t)_i$.

IV. DESCRIPTION OF INPUTS

A. Calculation of Initial Input Data

1. Given Information

The following information must be specified:

a. External conditions (u_e, ρ_e, μ_e, T_e, Y_{ke}) $k = 1, \ldots 7$ representing species $O, N, NO, O_2^-, O_2 . N_2$, and NO^+.

b. Wall conditions (T_o, $(Y_k)_o$) $k = 1, \ldots 7$.

(1) Initial compressible skin friction coefficient $c_f \equiv \tau_o / \rho_e u_e^2$.

(2) Initial compressible Reynolds number based on momentum thickness - $R_\theta \equiv \rho_e u_e \theta / \mu_e$.

c. Initial temperature variation with velocity ratio $T(u/u_e)$ through viscous layer.

d. Initial species mass fraction variation with velocity ratio $Y_k(u/u_e)$ $k = 1, \ldots 7$ through viscous layer.

2. Calculation of $\sigma/\overline{\mu}$

As a first step in determining the input data the parameter $\sigma/\overline{\mu}$ must be related to the incompressible skin friction coefficient $\overline{c}_f$. This procedure varies depending on whether the substructure or sublayer hypothesis is utilized.

a. Calculation of $\sigma/\bar{\mu}$ According to Substructure Hypothesis

For the substructure hypothesis, take

$$\frac{\bar{\mu}}{c} = \mu_s = \mu\left(T_s(Y_k)_s\right) \tag{92}$$

where μ_s denotes the viscosity of the mixture evaluated at the temperature T_s, and composition $(Y_k)_s$ where these latter are given by

$$T_s = \frac{1}{430}\int_0^{430} T d\zeta \tag{93}$$

$$(Y_k)_s = \frac{1}{430}\int_0^{430} Y_k d\zeta \tag{94}$$

$$k=1,\ldots 7$$

In accordance with items c and d, T and Y_k are known functions of u/u_e. Furthermore, from the Eqs. (AIII-1) through (AIII-6) given in Ref. 1 and the relations

$$\varphi = \sqrt{\frac{2}{C_f}} \tag{95}$$

$$\zeta_\delta = \exp\left\{\frac{\varphi-12.35}{2.43} + 2.03\right\} \tag{96}$$

and

$$\frac{u}{u_e} = \frac{1}{\varphi}\frac{\bar{u}}{u_\tau} \tag{97}$$

one can obtain the correspondence between the velocity ratio u/u_e and ζ for any particular value of $\overline{c}_f$;

$$\frac{u}{u_e} = \frac{u}{u_e}(\zeta;\ \overline{c}_f)\ . \tag{98}$$

Thus the integrals appearing in (93) and (94) can be evaluated (numerically if necessary) and will depend only on a choice of $\overline{c}_f$. Thus also $\sigma/\overline{\mu}$ will be related uniquely to $\overline{c}_f$; i.e.:

$$\frac{\overline{\mu}}{\sigma} = \frac{\overline{\mu}}{\sigma}(\overline{c}_f)\ . \tag{99}$$

b. <u>$\sigma/\overline{\mu}$ According to Sublayer Hypothesis</u>

For the sublayer hypothesis, take

$$\frac{\sigma\mu_s}{\overline{\mu}} = \frac{1}{10.6}\int_0^{56.18} \frac{\rho_s}{\rho}\frac{d\tilde{\psi}}{\sqrt{2\tilde{\psi}}} \tag{100}$$

where ρ_s and μ_s denote the density and viscosity of the mixture at $\tilde{\psi} = 56.18$. In general, the density is related to the temperature and species by

$$\frac{\rho_e}{\rho} = \frac{T}{T_e}\left(\sum_{k=1}^{7}\frac{Y_k}{M_k}\right)_e\left(\sum_{k}^{7}\frac{Y_k}{M_k}\right)^{-1} \tag{101}$$

where the M_k denote the molecular weights of the individual species and are given. Since the Y_k and T are related to the velocity ratio through c and d above we have

$$\frac{\rho_e}{\rho} = \frac{\rho_e}{\rho}\left(\frac{u}{u_e}\right) . \tag{102}$$

Now relate ρ_e/ρ to $\tilde{\psi}$ by the relation

$$\frac{u}{u_e} = \frac{\sqrt{2\tilde{\psi}}}{\varphi} \tag{103}$$

so that, as in the sub-structure case, there can be written formally

$$\frac{\sigma}{\overline{\mu}} = \frac{\sigma}{\overline{\mu}}\,(\overline{C}_f) . \tag{104}$$

3. <u>Calculation of φ</u>

a. With C_f given, solve for $\overline{C}_f$ (by iteration) from the following equation

$$\frac{C_f}{\overline{C}_f} = \frac{\rho_w \mu_w}{\rho_e}\,\frac{\sigma}{\overline{\mu}} . \tag{105}$$

b. With R_θ given, use Eq. (105) and

$$\frac{R_\theta}{R_{\bar{\theta}}} = \frac{1}{\mu_e}\frac{\bar{\mu}}{\sigma} \tag{106}$$

$$\bar{C}_f = \bar{C}_f(R_{\bar{\theta}}) \tag{107}$$

where Eq. (107) is given graphically in Fig. 5. The solution for $\bar{C}_f$ is again obtained by iteration.

4. Calculation of φ, ζ_δ, ψ_M

Once an initial value of $\bar{C}_f$ has been obtained the corresponding values of φ and ζ_δ follow from (95) and (96), while ψ_M is obtained from

$$\psi_M = -30.81 + 2.43\,\zeta_1 \ln \zeta_1 + 2.47\,\zeta_1 + (\zeta_\delta - \zeta_1)\varphi + 1.7\,\zeta_\delta \tag{108}$$

where $\zeta_1 = 0.131\,\zeta_\delta$.

5. Calculation of Initial Profiles $T(\psi)$, $Y_k(\psi)$, $G(\psi)$

From the given inputs there is available $T(u/u_e)$ and $Y_k(u/u_e)$. $G(u/u_e)$ is obtained from

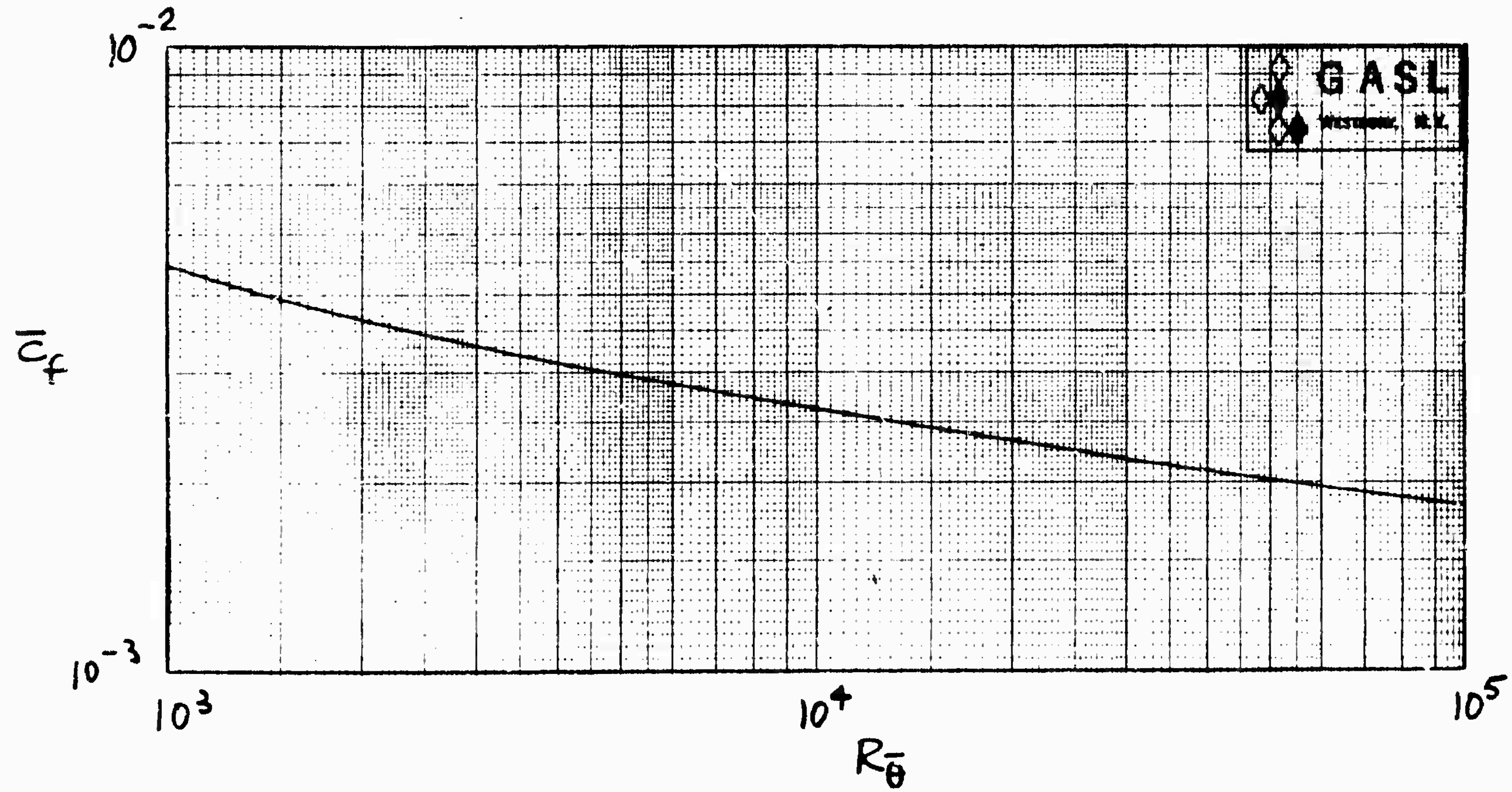

FIG. 5 - VARIATION OF $\bar{c}_f$ VS $R_{\bar{\theta}}$ FOR CONSTANT DENSITY FLOW

$$G = \frac{\Sigma Y_k h_k}{H_e} + \left(\frac{u}{u_e}\right)^2 \frac{u_e^2}{2H_e} \quad .$$

From the parametric relations

$$\frac{u}{u_e} = \frac{\bar{u}}{\bar{u}_e} = \text{function of } \zeta$$

$$\psi = \psi(\zeta)$$

given in Appendix III of Ref. 1 there is tabulated the relation

$$u/u_e = u/u_e(\psi)$$

where G, T and Y_k can be obtained as functions of ψ. These are plotted in graphical form from which the desired values corresponding to the previously selected ψ-mesh points ψ_i are read off.

6. <u>Numerical Example (Sublayer Hypothesis)</u>

a. External conditions

$$\rho_e = 1.344 \times 10^{-3} \text{ slugs/ft}^3$$

$$u_e = 2120 \text{ ft/sec}$$

$$T_e = 122^\circ \text{K}$$

$$\mu_e = .4926 \times 1.153 \times 10^{-8} \text{ \#/ft-sec}$$

$$\left.\begin{aligned} (Y_5)_e &= .232 \\ (Y_6)_e &= 0.768 \\ (Y_k)_e &= 0;\ k = 1,2,3,4,7 \end{aligned}\right\}\ \text{undissociated air}$$

b. Wall conditions

$$T_o = 306\ {}^\circ K$$

$$(Y_k)_o = (Y_k)_e;\ k = 1,\ \ldots\ 7\ .$$

c. Skin friction coefficient

$$C_f = .0013\ .$$

d. Temperature distribution

$$T = T_o + (T_{s_e} - T_o)\frac{u}{u_e} - (T_{s_e} - T_e)\frac{u^2}{u_e^2}$$

(Crocco integral; $P_e = 1$).

e. Species distribution

$$Y_k(u/u_e) = \text{constant} = (Y_k)_e\ .$$

Combining e, (101) and (103) gives, using the numerical data

$$\frac{\rho_e}{\rho} = 2.51 + 0.22\,\frac{\sqrt{2\tilde{\psi}}}{\varphi} - 1.73\,\frac{2\tilde{\psi}}{\varphi^2}$$

$$\frac{\rho_e}{\rho_s} = 2.51 + \frac{2.33}{\varphi} - \frac{194}{\varphi^2}$$

so that from (100)

$$\frac{\sigma\mu_s}{\bar{\mu}} = \frac{1}{10.6}\;\frac{\displaystyle\int_0^{56.18}\left[\frac{2.51}{\sqrt{2\tilde{\psi}}} + \frac{0.22}{\varphi} - 1.73\,\frac{\sqrt{2\tilde{\psi}}}{\varphi^2}\right]d\tilde{\psi}}{2.51 + \dfrac{2.33}{\varphi} - \dfrac{194}{\varphi^2}}$$

$$= \frac{2.51 + \dfrac{1.165}{\varphi} - \dfrac{64.67}{\varphi^2}}{2.51 + \dfrac{2.33}{\varphi} - \dfrac{194}{\varphi^2}}\,.$$

Now take an initial guess of $\bar{C}_f = 2\text{x}10^{-3}$ so that from (95)

$$\varphi = 22.4$$

for which

$$\frac{\rho_s}{\rho_e} = 0.451$$

$$\frac{\mu_s}{\mu_e} = 2.06$$

and

$$\frac{\sigma\mu_s}{\bar{\mu}} = 1.095 \ .$$

From the given data $\dfrac{\rho_o\mu_o}{\rho_e\mu_e} = 1.131$ so that from (105)

$$c_f = \frac{\rho_o\mu_o}{\rho_e\mu_e}\,\frac{\mu_e}{\mu_s}\,\frac{\mu_s\sigma}{\bar{\mu}}\,\bar{c}_f = .0012 < .0013 \ .$$

A second guess of $\bar{c}_f = .0025$ yields

$$c_f = .00163 > .0013 \ .$$

A linear interpolation gives as a third guess $\bar{c}_f = .00212$ for which one obtains

$$c_f = .00131 \approx .0013$$

which is the required result.

B. Input Formats for IBM Programs

In this section, the input formats for each of the two program decks - Substructure / Reference Hypothesis, and Sublayer Hypothesis, will be described in detail. Refer to the section on Nomenclature for allied information.

The term "card" refers to the standard IBM data processing card consisting of 12 rows and 80 columns. The term "format" refers to the mode of input. Symbolically, these modes may be defined as follows:

I	integer	$\pm$ **XX**	(no decimal point)
E	floating point	$\pm$ **X.XXX** $\pm$ YY	(YY is the exponent to the base 10. $\pm$ **X.XXX**.$10^{(YY)}$).

For the **E** mode, the decimal point may be shifted from the position indicated in the above example and the maximum number of significant figures is governed by the field width assigned for each "word" of data. The plus (+) sign may be omitted in all cases, except for the sign immediately preceding the exponent for the **E** mode. An additional format is the Hollerith mode which consists of alpha-numerical information, and for our purposes, will be utilized exclusively for an identification input card, which will subsequently be printed as a title at the head of the output listing. It is good practice to "right-adjust" data words within the indicated field; that is, the word must be shifted to the extreme right of the field.

1. Substructure and Reference Hypotheses

CARD	COLUMN	DESCRIPTION	FORMAT
1	1	Punch the number 0	
	2-72	Title information	H
2	6	Punch the number "1"	
2	14-15	M - Number of coarse mesh points in "ψ" direction, ≤ 40	I
		Total number of species = 7	I
	55	Punch the number "1"	I
	60	Maximum number of iterations on "ΔX" if finite rate chemistry option is requested (≤ 5) [See Eq. (50)]	I
	64-65	Number of fine mesh points in "ψ" direction, ≤ 25	I
	69-70	m - Print cycle number - print properties at every m^{th} χ-step, ≤ 10	I
3	4-5	M - Punch same number as in cols. 14-15, card 2	I
	10	Chemistry option: Punch "1" if finite-rate chemistry requested; punch "0" if no chemistry	I
	15	"G" input profile option "1" - input temperature in $^{\circ}K$ "2" - input stagnation enthalpy ratios (for "1" and "2": inputs on 8th set of cards A+1 through C)	I
	20	Reference or substructure hypothesis option "0" - substructure hypothesis "1" - reference hypothesis	I

CARD	COLUMN	DESCRIPTION	FORMAT
4	1-15	"$\Delta\psi$" for coarse mesh = $(\psi_M - \psi_1)/M$	E
	31-45	Final value of "χ"	E
	61-75	"φ_o" - initial φ	E
5	1-15	"$(\zeta\delta)_o$" - initial $\zeta\delta$	E
	16-30	"HE" - reference stagnation enthalpy (ft^2/sec^2)	E
	31-45	"$\Delta\xi$" - CSI step size	E
	46-60	"DPSY" - "ψ" step size between wall and "ψ_1"	E
6	1-15	"TROLL" - tolerance for iteration on "ΔX" for chemistry (approx. 0.05) [see Eq. (50)]	E
	16-30	"EPS" - tolerance for adding point to species or energy solution matrix (approx. 0.001) [see Eqs. (45) and (46)]	E
7	1-15	"P_e" - Prandtl number	E
	16-30	"S_e" - Schmidt number	E
	31-45	"ψ_1" - first numerical ψ value after wall	E
	46-60	"T_e" - reference temperature ($^\circ K$)	E
	61-75	"u_e" - reference velocity (ft/sec)	E
8	1-15	"ρ_e" - reference density ($slugs/ft^3$)	E
	16-30	"μ_e" - reference viscosity ($lb\text{-}sec/ft^2$)	E
	46-60	Initial value of $\frac{d}{dX}(\ln\sigma)$ (sub-structure version only). Use zero if not known.	E
	73-75	"SS" - punch 1.0 if $\frac{d}{dX}(\ln\sigma)$ (cols. 50-60) is not zero	E

CARD	COLUMN	DESCRIPTION	FORMAT
9,..A	1-15,16-30, ..61-75 1-15,16-30	Initial wall species for species 1 to 7. The species are O,N, NO,O_2^-,O_2,N_2 and NO^+.	E
A+1,A+2..B	1-15,16-30, ..61-75 1-15, etc.	Values of Y_1 at all fine mesh points along initial ψ-mesh line from $\psi=\psi_1$ to point immediately below $\psi=\psi_2$	E
B+1,B+2..C	1-15,16-30, ..61-75 1-15, etc.	Values of Y_1 at all coarse mesh points along initial ψ-mesh line from $\psi=\psi_2$ to $\psi=\psi_M$, inclusive	E

[Repeat cards "A+1" to "C" for remaining species Y_2 through Y_7, and then for "G" profile. Thus there are 8 sets of cards designated A+1 through C]

CARD	COLUMN	DESCRIPTION	FORMAT
C+1..D	1-15,16-30, ..61-75 1-15,16-30	$(Y_k)_e$ for k = 1,2,...,7 (Mass fractions at edge of boundary layer)	E
D+1		Wall temperature function vs. "X" $(T_W)_1 = A_1 + B_1 X$, for $X \leq X_1$ $(T_W)_2 = A_2 + B_2 X$, for $X \geq X_1$	E
	1-15	A_1, (°K)	
	16-30	A_2, (°K)	
	31-45	B_1, °K/units of X_1	
	46-66	B_2, °K/units of X_1	
	61-75	$X_i(\rho_e u_e/\mu_e)$, where X_1 is in feet	
D+2..E	1-15,16-30, ..61-75 1-15,16-30	Molecular weights, M_k, for species 1 to 7 These values are: M_1=16.0, M_2=14.0, M_3=30.0, M_4=32.0, M_5=32.0, M_6=28.0, M_7=30.0	E

2. Sublayer Hypothesis

CARD	COLUMN	DESCRIPTION	FORMAT
1	1	Zero	
	2-72	Title information	H
2	4-5	Number of fine mesh points in "ψ" direction, ≤ 25	I
	9-10	M - Number of coarse mesh points in "ψ" direction, ≤ 40	I
	14-15	<u>TOTAL</u> number of mesh points in "ψ" direction (sum of values in cols. 4-5 and 9-10)	I
	19-20	M (same as in cols. 9-10)	I
	24-25	Punch same as in cols. 14-15	I
	30	"G" input profile option Punch "1" - if temperature in degrees Kelvin are input on 8th set of cards A+1 through C Punch "2" - if stagnation enthalpy ratio (h/h_e) are input on 8th set of cards A+1 through C	I
	35	Punch a "1"	I
	40	Punch a "7"	I
	44-45	m - Print cycle number - print properties at every m^{th} χ-step, ≤ 10	I
	50	Chemistry option: Punch "1" if finite-rate chemistry requested; Punch "0" if no chemistry	I

CARD	COLUMN	DESCRIPTION	FORMAT
2	55	Punch "1"	
	60	Chemistry option for (O_2^-) "4" - (O_2^-) is not included in chemistry reactions "5" - (O_2^-) is included in chemistry reactions	I
3	11	Punch "1"	I
	20	Maximum number of iterations on "Δ X" if chemistry option is requested, ≤ 5 [see Eq. (50)]	I
4	1-15	"$\Delta\,\psi$" for coarse mesh region between $\psi = 56.18$ and $\psi = \psi_M$	E
	31-45	"ξ_F" = final value of CSI	E
	61-75	"φ_o" - initial φ	E
5	1-15	"$\zeta\delta_o$" - initial ZETA DELTA	E
	16-30	h_e - reference stagnation enthalpy (ft^2/sec^2)	E
	31-45	"$\Delta\,\xi$" - ξ step size	E
	46-60	"DPSY" - $\Delta\,\psi$ for "ψ" between wall and $\psi = \psi_1$	E
6	1-15	"TROLL" - tolerance for iteration on "Δ X" if chemistry option is requested, approx. .05 [see Eq. (50)]	E
	16-30	"ERS" - tolerance on $\bar{D}$ for adding pt. to solution matrix, approx. 0.01 [see Eqs. (45) and (46)]	E
7	1-15	P_e - Prandtl number	E
	16-30	S_e - Schmidt number	E
	31-45	ψ_1 - First numerical "ψ" value above wall	E

CARD	COLUMN	DESCRIPTION	FORMAT
7	46-60	T_e - reference temperature (°K)	E
	61-75	u_e - reference velocity (ft/sec)	E
8	1-15	ρ_e - reference density (slugs/ft^3)	E
	16-30	μ_e - reference viscosity (lb-sec/ft^2)	E
	46-60	Initial value of $\frac{d}{dx}(\ln \sigma)$ (use zero if not known)	E
	61-75	"SS" - punch "1.0" if cols. 46-60 is not zero or blank	E
9,..A	1-15, 16-30, ..61-75 1-15, 16-30	Initial wall species for species 1 to 7. The species are O, N, NO, O_2^-, O_2, N_2 and NO^+	E
A+1, A+2..B	1-15, 16-30, ..61-75 1-15, etc.	Values of Y_1 at all fine mesh points along initial ψ-mesh line from $\psi=\psi_1$ to point immediately below $\psi=56.18$	E
B+1, B+2..C	1-15, 16-30, ..61-75 1-15, etc.	Values of Y_1 at all coarse mesh points along initial ψ-mesh line from $\psi=56.18$ through $\psi=\psi_M$	E

[Repeat cards A+1 through C for remaining species Y_2 through Y_7 and then for G profile, thus there are 8 sets of cards designated A+1 through C]

CARD	COLUMN	DESCRIPTION	FORMAT
C+1..D	1-15, 16-30, ..61-75 1-15 16-30	$(Y_k)_e$ for k = 1, 2 . . . 7 (Mass fractions for edge of boundary layer)	E

CARD	COLUMN	DESCRIPTION	FORMAT
D+1		Wall temperature function vs. "X" $(T_W)_1 = A_1 + B_1\ X$, for $X \le X_1$ $(T_W)_2 = A_2 + B_2\ X$, for $X \ge X_1$	E
	1-15	A_1 ($^\circ K$)	
	16-30	A_2 ($^\circ K$)	
	31-45	B_1 $^\circ K$/units of X_1	
	46-60	B_2 $^\circ K$/units of X_1	E
	61-75	$X_1 \cdot (\rho_e u_e/\mu_e)$, where X_1 is in feet	
D+2..E	1-15,16-30, ..61-75	Molecular weights M_k for species 1 to 7	E
	1-15,16-30	These values are: M_1=16.0, M_2=14.0, M_3=30.0, M_4=32.0, M_5=32.0, M_6=28.0, M_7=30.0	

V. DESCRIPTION OF OUTPUTS

The output of the program consists of a title page containing program title, names of originator and programmer, a title statement describing the type of computer run, date, etc., and then 17 lines listing the numerical values of all input data.

For each step in the χ direction (CSI), or horizontal coordinate, results are printed in a three page format listing the following information:

Page 1 - The value of "CSI" followed by a seven column table. Each row of the table represents data for a value of "PSI," or vertical coordinate. The columns are, from left to right, (PSI), stagnation enthalpy ratio, G, temperature (TEMP), density (RHO), molecular weight of the mixture, (M), electron mass fraction (ELEC. CON), and electron density in particles per cc.

Page 2 - An eight-column table where the first column contains each value of PSI, while the remaining columns are the mass fractions of each specie. The species are, from left to right, O, N, [illegible], O_2^-, O_2, N_2, and NO^+.

Page 3 - A five-column table where the first column contains the vertical "ZETA" variable corresponding to each

"PSI" value. The remaining columns are, from left to right, incompressible viscosity (I-VIS), compressible viscosity (C-VIS), velocity (U-BAR), and the physical vertical coordinate associated with PSI and ZETA, the (Y coordinate) in feet.

Following the data table on page 2 are printed two integers, LE and LS. They indicate the number of PSI values used in the energy and species solutions, respectively.

Following the data table on page 3, except for CSI = 0, are printed the values of X-coordinate, PHI, ZETA DELTA, DDCHI LOG SIGMA, SIGMA OVER MU-BAR, heat transfer Q-DOT in BTU per square foot-sec, and CF.

Of the preceding quantities, stagnation enthalpy, density, temperature, velocity, and viscosity are normalized with respect to the input edge conditions.

Examples of the output described herein, appear in Appendix 2.

VI. OPERATING PROCEDURE

The program was written for the IBM 709/90/94 digital computers and uses the IBM FORTRAN II monitor system.

The FORTRAN II monitor system has standard tape designations, which are:

A2 - Standard input tape

A3 - Standard BCD output tape

A1 - Systems tape

A5 - Binary tape for restart procedure.

An IOU subroutine is included in the object deck to ensure compatibility with the logical assignment of tapes.

"Checkpoint" Procedure

If a restart option is to be implemented a tape must be mounted on logical unit A5. Depressing sense switch 6 at any time during the course of a run will dump the contents of core memory onto tape A5 and then terminate the run. Tape A5 is dismounted and saved for future use. Tape A3 may then be listed.

To restart at a future time, the binary tape that was saved, is again mounted on logical unit A5 and a small binary object

deck labelled "RESTART," is used as the program deck. The program will read the contents of tape A5 and processing will commence from the point where it was formerly dumped. Processing will continue until Sense Switch 6 is again depressed for a second dump onto tape A5 for a future second restart, etc.

To protect the original information on tape A5, a second tape may be mounted on a unit to be designated as A5 after the original tape has been read by the 7094. The unit with the original tape should be dialed off and the tape dismounted. Core memory will be dumped on the second tape for a future restart.

The program is normally terminated by specifying a value of CSI FINAL on input card 3. When the program has calculated the data for the first value of CSI which is greater than CSI FINAL, the program will automatically process additional sets of input data, or in the absence of such cards, will terminate. A maximum time limit should be specified in the instructions to the operator in this case, in the event of a failure of the program to achieve a value of CSI FINAL.

There are several other program stops, caused by numerical errors, wherein the program will print a code number, and in some cases an alphabetical statement describing the error.

A list of these error stops is given in Appendix 1. The program will then either process the next data case, or terminate just as in the case of a normal stop at CSI FINAL.

Several options for methods of numerical calculation of the program can be specified on input card 8 and are described in Section IV. There is one option controlled by Sense Switch 1 as follows:

SENSE SWITCH 1

UP - Compressible viscosities are not computed and printed. In this case, either the number 0 or the values of incompressible viscosity are printed, the latter for values of PSI greater than PSI DELTA.

DOWN - Compressible viscosities are computed and printed.

Sense Switch 1 instructions need be given to the machine operator only if the Sense Switch 1 DOWN option is desired.

See Eqs. (15) and (16) for the equations defining incompressible and compressible viscosities.

NOMENCLATURE

G	stagnation enthalpy ratio = H/H_e
H	stagnation enthalpy = $h + u^2/2$
h_i	static enthalpy of species; $h = \sum_k h_k Y_k$
P_e	effective Prandtl number
$\dot{q}$	heat transfer per unit time per unit area
S_e	effective Schmidt number
T	static temperature
u	mass averaged velocity in axial direction
M_k	molecular weight of species k
X	axial coordinate
z	normal coordinate

Greek Symbols

δ	boundary layer thickness
ζ	transformed variable defined by Eq. (35) of Ref. 1
η, s	transformed variables defined by Eq. (53) of Ref. 1
$\sigma(x), \eta(x), \xi(x)$	stretching function (see Eq. (15) of Ref. 1)
θ	momentum thickness
μ	laminar viscosity coefficient
ϵ	kinematic viscosity coefficient

χ	transformed variable (see Eq. (47)) of Ref. 1
ρ	mass density
$\rho\varepsilon$	eddy viscosity
γ	shear stress
φ	$\bar{U}_e/U_\tau$
$\tilde{\Psi}$	stream function defined by Eq. (57) of Ref. 1

<u>Subscripts</u>

e	free stream
$(\bar{\ })$	incompressible state

REFERENCES

1. Rosenbaum, H., Compressible Turbulent Boundary Layer with Application to Hydrogen Dumping and Combustion, GASL TR-514, March 1965.

2. Thermal Laboratory, Dow Chemical JANAF Interim Thermochemical Tables, December 1960 et seq.

3. Moretti, G., A New Technique for the Numerical Analysis of Nonequilibrium Flows, AIAA Journal, Vol. 3, No. 2, February 1955, pp. 223-229.

4. De Groat, J. and Abbett, M., A Computation of One-Dimensional Combustion of Methane, AIAA Journal, Vol. 3, No. 2, February 1965, pp. 381-383.

APPENDIX 1

LIST OF ERROR STOPS

APPENDIX 1

LIST OF ERROR STOPS

PRINTED NUMBER	DESCRIPTION OF ERROR
1	An element in Column 2 of species or energy difference equation matrix is equal to zero
6	The number of ψ values given to Subroutine HERB is greater than 149
8	A value of ψ greater than PSI DELTA plus 1/2 DELTA PSI has been computed by Subroutine HERB
9	Subroutine HERB has taken more than 15 iterations to compute a value of ZETA
25	No value of "ZETA" is greater than 430
26	Subroutine HERB has computed a value of PSI DELTA less than 1/2 DELTA PSI

APPENDIX 2

SAMPLE OUTPUT OF IBM SHEETS

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```
         TURBULENT  TRANSPORT  ANALYSIS
              ORIGINATOR -   H. ROSENBAUM
              PROGRAMMER -  B. BELLOW
REFERENCE HYPOTHESIS

COARSE PSI STEP=   5232.00   INITIAL CSI=-0.          FINAL CSI= 0.12E 10     CSI STEP TOLERANCE=   0.20000E 04

INITIAL PHI=      27.11200   ZETA DELTA=   3282.443   HE=  0.2240800E 09      CSI STEP=      0.5000E 02

FINE PSI STEP=       0.100   WALL TEMP TOL= 0.05000   D-BAR TOL= 1.00E-03     PSI ONE=            0.100

DELTA=                 -0.


PRANDTL NUMBER=  1.00        SCHMIDT NUMBER= 1.00     TE=      1511.10        UE=    20248.00

RHO E=  0.2120000E-03        MU E=  0.1100000E-05     TR=       300.00        DD CHI LOG SIG= -0.


MAX NO. OF CSI CUTBACKS=    5     MAX NO. OF CSI STEPS BEFORE DOUBLING=  500

NO OF SPECIES COARSE PSI POINTS=   15     NO. OF COARSE G POINTS=   15     NO. OF FINE PSI POINTS=   25

NO. OF SPECIES=    7     MAX NO. OF WALL TEMP ITERATIONS=    5     PRINT CYCLE NUMBER=    1


THE WALL TEMPERATURE FUNCTION VERSVS X IS
            3000.0000+     -0.    X FOR X LESS THAN      0.2400000E 08
            3000.0000+     -0.    X FOR X GREATER THAN  0.2400000E 08


THE FOLLOWING ARE MOLECULAR WEIGHTS FOR THE SAME SPECIES
 1.6000000E 01  1.4000000E 01  3.0000000E 01  3.2000000E 01  3.2000000E 01  2.8000000E 01  3.0000000E 01
```

	PSI	O	N	NO	O2M	O2	N2	NOP	
0	0.	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	0
1	0.	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	1
1	1.0000000E-01	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	1
2	2.0937999E 02	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	2
3	4.1865999E 02	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	3
4	6.2793999E 02	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	4
5	8.3721999E 02	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	5
6	1.0465000E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	6
7	1.2557800E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	7
8	1.4650600E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	8
9	1.6743400E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	9
10	1.8836200E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	10
11	2.0928999E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	11
12	2.3021800E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	12
13	2.5114599E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	13
14	2.7207400E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	14
15	2.9300199E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	15
16	3.1393000E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	16
17	3.3485799E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	17
18	3.5578600E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	18
19	3.7671399E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	19
20	3.9764200E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	20
21	4.1856999E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	21
22	4.3949799E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	22
23	4.6042598E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	23
24	4.8135399E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	24
25	5.0228198E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	25
26	5.2320998E 03	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	26
27	1.0464100E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	27
28	1.5696100E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	28
29	2.0928099E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	29
30	2.6160100E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	30
31	3.1392100E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	31
32	3.6624100E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	32
33	4.1856099E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	33
34	4.7088099E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	34
35	5.2320099E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	35
36	5.7552099E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	36
37	6.2784100E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	37
38	6.8016099E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	38
39	7.3248100E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	39
40	7.8480099E 04	9.9999999E-16	9.9999999E-16	1.0000000E-20-0.		2.3200000E-01	7.6799999E-01	1.0000000E-20	40

CSI =-0.

	PSI	G	TEMP	RHO	W	ELEC. CON.	ELEC. DENS.	
0	0.	1.6854981E-01	1.9853089E 00	5.0369993E-01	2.8836251E 01	1.8315018E-25	1.1089147E-02	0
1	1.0000000E-01	1.6854981E-01	1.9826468E 00	5.0437627E-01	2.8836251E 01	1.8315018E-25	1.1104037E-02	1
1	1.0000000E-01	2.6200000E-01	2.9821335E 00	3.3533040E-01	2.8836251E 01	1.8315018E-25	7.3824273E-03	1
2	2.0937999E 02	5.9800000E-01	4.4696514E 00	2.2373109E-01	2.8836251E 01	1.8315018E-25	4.9255258E-03	2
3	4.1865999E 02	6.3239999E-01	4.4007493E 00	2.2723403E-01	2.8836251E 01	1.8315018E-25	5.0025443E-03	3
4	6.2793999E 02	6.5369999E-01	4.3371617E 00	2.3056553E-01	2.8836251E 01	1.8315018E-25	5.0759886E-03	4
5	8.3721999E 02	6.6919999E-01	4.2807579E 00	2.3360349E-01	2.8836251E 01	1.8315018E-25	5.1428705E-03	5
6	1.0465000E 03	6.8139999E-01	4.2302804E 00	2.3639095E-01	2.8836251E 01	1.8315018E-25	5.2042374E-03	6
7	1.2557800E 03	6.9149999E-01	4.1849368E 00	2.3895223E-01	2.8836251E 01	1.8315018E-25	5.2606251E-03	7
8	1.4650600E 03	7.0009999E-01	4.1434202E 00	2.4134651E-01	2.8836251E 01	1.8315018E-25	5.3133360E-03	8
9	1.6743400E 03	7.0760000E-01	4.1051825E 00	2.4359453E-01	2.8836251E 01	1.8315018E-25	5.3628269E-03	9
10	1.8836200E 03	7.1429999E-01	4.0702037E 00	2.4568795E-01	2.8836251E 01	1.8315018E-25	5.4089144E-03	10
11	2.0928999E 03	7.2029999E-01	4.0372815E 00	2.4769142E-01	2.8836251E 01	1.8315018E-25	5.4530216E-03	11
12	2.3021800E 03	7.2570000E-01	4.0058233E 00	2.4963658E-01	2.8836251E 01	1.8315018E-25	5.4958450E-03	12
13	2.5114599E 03	7.3069999E-01	3.9767130E 00	2.5146396E-01	2.8836251E 01	1.8315018E-25	5.5360754E-03	13
14	2.7207400E 03	7.3519999E-01	3.9479094E 00	2.5329862E-01	2.8836251E 01	1.8315018E-25	5.5764662E-03	14
15	2.9300199E 03	7.3949999E-01	3.9218526E 00	2.5498154E-01	2.8836251E 01	1.8315018E-25	5.6135164E-03	15
16	3.1393000E 03	7.4349999E-01	3.8968540E 00	2.5661726E-01	2.8836251E 01	1.8315018E-25	5.6495273E-03	16
17	3.3485799E 03	7.4719999E-01	3.8724078E 00	2.5823726E-01	2.8836251E 01	1.8315018E-25	5.6851925E-03	17
18	3.5578600E 03	7.5070000E-01	3.8491637E 00	2.5979669E-01	2.8836251E 01	1.8315018E-25	5.7195238E-03	18
19	3.7671399E 03	7.5399999E-01	3.8267703E 00	2.6131696E-01	2.8836251E 01	1.8315018E-25	5.7529931E-03	19
20	3.9764200E 03	7.5709999E-01	3.8049299E 00	2.6281693E-01	2.8836251E 01	1.8315018E-25	5.7860155E-03	20
21	4.1856999E 03	7.6010000E-01	3.7844575E 00	2.6423866E-01	2.8836251E 01	1.8315018E-25	5.8173155E-03	21
22	4.3949799E 03	7.6289999E-01	3.7640642E 00	2.6567028E-01	2.8836251E 01	1.8315018E-25	5.8488332E-03	22
23	4.6042598E 03	7.6560000E-01	3.7446288E 00	2.6704917E-01	2.8836251E 01	1.8315018E-25	5.8791898E-03	23
24	4.8135399E 03	7.6819999E-01	3.7259851E 00	2.6838540E-01	2.8836251E 01	1.8315018E-25	5.9086075E-03	24
25	5.0228196E 03	7.7069999E-01	3.7079868E 00	2.6968812E-01	2.8836251E 01	1.8315018E-25	5.9372874E-03	25
26	5.2320998E 03	7.7299999E-01	3.6894345E 00	2.7104425E-01	2.8836251E 01	1.8315018E-25	5.9671431E-03	26
27	1.0464100E 04	8.1689999E-01	3.3279895E 00	3.0048172E-01	2.8836251E 01	1.8315018E-25	6.6152202E-03	27
28	1.5696100E 04	8.5319999E-01	2.9783464E 00	3.3575678E-01	2.8836251E 01	1.8315018E-25	7.3918142E-03	28
29	2.0928099E 04	8.8460000E-01	2.6380984E 00	3.7906091E-01	2.8836251E 01	1.8315018E-25	8.3451715E-03	29
30	2.6160100E 04	9.1140000E-01	2.3206966E 00	4.3090511E-01	2.8836251E 01	1.8315018E-25	9.4865412E-03	30
31	3.1392100E 04	9.3390000E-01	2.0350259E 00	4.9139423E-01	2.8836251E 01	1.8315018E-25	1.0818232E-02	31
32	3.6624100E 04	9.5239999E-01	1.7865437E 00	5.5974001E-01	2.8836251E 01	1.8315018E-25	1.2322891E-02	32
33	4.1856099E 04	9.6730000E-01	1.5790420E 00	6.3329539E-01	2.8836251E 01	1.8315018E-25	1.3942241E-02	33
34	4.7088099E 04	9.7880000E-01	1.4080664E 00	7.1019377E-01	2.8836251E 01	1.8315018E-25	1.5635188E-02	34
35	5.2320099E 04	9.8740000E-01	1.2769102E 00	7.8314042E-01	2.8836251E 01	1.8315018E-25	1.7241137E-02	35
36	5.7552099E 04	9.9330000E-01	1.1818815E 00	8.4610847E-01	2.8836251E 01	1.8315018E-25	1.8627403E-02	36
37	6.2784100E 04	9.9710000E-01	1.1215891E 00	8.9159211E-01	2.8836251E 01	1.8315018E-25	1.9628742E-02	37
38	6.8016099E 04	9.9909999E-01	1.0886024E 00	9.1860900E-01	2.8836251E 01	1.8315018E-25	2.0223529E-02	38
39	7.3248100E 04	9.9990000E-01	1.0762664E 00	9.2913802E-01	2.8836251E 01	1.8315018E-25	2.0455330E-02	39
40	7.8480099E 04	1.0000000E 00	1.0742341E 00	9.3089578E-01	2.8836251E 01	1.8315018E-25	2.0494028E-02	40

LE= 40LS= 40

CSI = 0.50000000E 02

	PSI	G	TEMP	RHO	W	ELEC. CON.	ELEC. DENS.	
0	0.	1.6886638E-01	1.9853089E 00	5.0356380E-01	2.8825457E 01	2.3092252E-16	1.3977828E 07	0
1	1.0000000E-01	2.6040016E-01	2.9624240E 00	3.3748972E-01	2.8830127E 01	1.2811054E-17	5.1971387E 05	1
1	1.0000000E-01	2.6040016E-01	2.9624240E 00	3.3748971E-01	2.8830127E 01	1.2811157E-17	5.1971804E 05	1
2	2.0937999E 02	5.9775317E-01	4.4593205E 00	2.2420831E-01	2.8830966E 01	3.9759730E-20	1.0715539E 03	2
3	4.1865999E 02	6.3238949E-01	4.3986940E 00	2.2730559E-01	2.8831860E 01	1.4668344E-21	4.0078375E 01	3
4	6.2793999E 02	6.5369801E-01	4.3354585E 00	2.3062565E-01	2.8832443E 01	7.8931336E-22	2.1881443E 01	4
5	8.3721999E 02	6.6919885E-01	4.2792546E 00	2.3365814E-01	2.8832868E 01	5.4848264E-22	1.5405035E 01	5
6	1.0465000E 03	6.8139990E-01	4.2289371E 00	2.3644102E-01	2.8833200E 01	3.9844403E-22	1.1324240E 01	6
7	1.2557800E 03	6.9149979E-01	4.1837070E 00	2.3899941E-01	2.8833469E 01	2.9883294E-22	8.5850772E 00	7
8	1.4650600E 03	7.0009971E-01	4.1422951E 00	2.4139063E-01	2.8833692E 01	2.2934132E-22	6.6545949E 00	8
9	1.6743400E 03	7.0760131E-01	4.1041598E 00	2.4363522E-01	2.8833883E 01	1.7939071E-22	5.2536233E 00	9
10	1.8836200E 03	7.1429818E-01	4.0692280E 00	2.4572807E-01	2.8834047E 01	1.4290718E-22	4.2211202E 00	10
11	2.0928999E 03	7.2029773E-01	4.0363579E 00	2.4773040E-01	2.8834191E 01	1.1517826E-22	3.4297995E 00	11
12	2.3021800E 03	7.2570174E-01	4.0050002E 00	2.4967116E-01	2.8834321E 01	9.3597553E-23	2.8090003E 00	12
13	2.5114599E 03	7.3069466E-01	3.9758650E 00	2.5150174E-01	2.8834434E 01	7.7014728E-23	2.3282719E 00	13
14	2.7207400E 03	7.3520564E-01	3.9472260E 00	2.5332744E-01	2.8834540E 01	6.3502363E-23	1.9337086E 00	14
15	2.9300199E 03	7.3949912E-01	3.9211406E 00	2.5501352E-01	2.8834632E 01	5.3133020E-23	1.6287207E 00	15
16	3.1393000E 03	7.4349684E-01	3.8961351E 00	2.5664963E-01	2.8834717E 01	4.4727365E-23	1.3798531E 00	16
17	3.3485799E 03	7.4720052E-01	3.8717830E 00	2.5826589E-01	2.8834795E 01	3.7762757E-23	1.1723294E 00	17
18	3.5578600E 03	7.5069923E-01	3.8485572E 00	2.5982516E-01	2.8834867E 01	3.2085875E-23	1.0021068E 00	18
19	3.7671399E 03	7.5399808E-01	3.8261810E 00	2.6134527E-01	2.8834934E 01	2.7388369E-23	8.6039865E-01	19
20	3.9764200E 03	7.5710304E-01	3.8044212E 00	2.6284063E-01	2.8834996E 01	2.3451551E-23	7.4093989E-01	20
21	4.1856999E 03	7.6009585E-01	3.7838969E 00	2.6426682E-01	2.8835052E 01	2.0228473E-23	6.4257623E-01	21
22	4.3949799E 03	7.6290147E-01	3.7635875E 00	2.6569338E-01	2.8835106E 01	1.7459936E-23	5.5762506E-01	22
23	4.6042598E 03	7.6560107E-01	3.7441699E 00	2.6707174E-01	2.8835155E 01	1.5148880E-23	4.8632587E-01	23
24	4.8135399E 03	7.6819971E-01	3.7255321E 00	2.6840826E-01	2.8835201E 01	1.3204627E-23	4.2603073E-01	24
25	5.0228199E 03	7.7069146E-01	3.7074646E 00	2.6971669E-01	2.8835245E 01	1.1547803E-23	3.7439159E-01	25
26	5.2320998E 03	7.7300177E-01	3.6890413E 00	2.7106407E-01	2.8835287E 01	1.0058207E-23	3.2772642E-01	26
27	1.0464100E 04	8.1689885E-01	3.3278270E 00	3.0049245E-01	2.8835873E 01	6.5861008E-25	2.3789255E-02	27
28	1.5696100E 04	8.5319923E-01	2.9783046E 00	3.3576006E-01	2.8836129E 01	1.9575541E-25	7.9006300E-03	28
29	2.0928099E 04	8.8459913E-01	2.6380991E 00	3.7906042E-01	2.8836221E 01	1.8324601E-25	8.3495272E-03	29
30	2.6160100E 04	9.1139905E-01	2.3207097E 00	4.3090259E-01	2.8836246E 01	1.8310106E-25	9.4839416E-03	30
31	3.1392100E 04	9.3389902E-01	2.0350415E 00	4.9139045E-01	2.8836251E 01	1.8310038E-25	1.0815208E-02	31
32	3.6624100E 04	9.5239904E-01	1.7865594E 00	5.5973511E-01	2.8836252E 01	1.8310038E-25	1.2319432E-02	32
33	4.1856099E 04	9.6729904E-01	1.5790555E 00	6.3328995E-01	2.8836251E 01	1.8310038E-25	1.3938330E-02	33
34	4.7088099E 04	9.7679914E-01	1.4080785E 00	7.1018768E-01	2.8836251E 01	1.8310038E-25	1.5630803E-02	34
35	5.2320099E 04	9.8739916E-01	1.2769187E 00	7.8313522E-01	2.8836252E 01	1.8310038E-25	1.7236334E-02	35
36	5.7552099E 04	9.9329934E-01	1.1818873E 00	8.4610438E-01	2.8836252E 01	1.8310037E-25	1.8622247E-02	36
37	6.2784100E 04	9.9709942E-01	1.1215918E 00	8.9159001E-01	2.8836252E 01	1.8310038E-25	1.9623358E-02	37
38	6.8016099E 04	9.9909961E-01	1.0886025E 00	9.1860900E-01	2.8836252E 01	1.8310038E-25	2.0218030E-02	38
39	7.3248100E 04	9.9989976E-01	1.0762649E 00	9.2913926E-01	2.8836251E 01	1.8310038E-25	2.0449795E-02	39
40	7.8480099E 04	9.9999991E-01	1.0742340E 00	9.3089585E-01	2.8836251E 01	1.8310039E-25	2.0488459E-02	40
41	8.3712099E 04	1.0000000E 00	1.0742344E 00	9.3089557E-01	2.8836251E 01	1.8315016E-25	2.0494021E-02	41

LE= 40LS= 41

	ZETA	I-VIS	C-VIS	U-BAR	Y CO-ORDINATE	
1	4.4721359E-01	0.	0.	1.6495042E-02	1.2961858E-05	1
1	4.4721359E-01	1.0000000E 00	0.	1.6495042E-02	1.2961858E-05	1
2	2.3618221E 01	9.7229913E 00	0.	4.6425159E-01	1.2758143E-03	2
3	3.9430251E 01	1.6193292E 01	0.	5.1007361E-01	2.2983808E-03	3
4	5.4132605E 01	2.2204036E 01	0.	5.3847138E-01	3.2367633E-03	4
5	6.8187280E 01	2.7933065E 01	0.	5.5916519E-01	4.1214891E-03	5
6	8.1787707E 01	3.3460015E 01	0.	5.7546577E-01	4.9670025E-03	6
7	9.5042435E 01	3.8829581E 01	0.	5.8892761E-01	5.7817473E-03	7
8	1.0802037E 02	4.4070133E 01	0.	6.0039969E-01	6.5712438E-03	8
9	1.2076883E 02	4.9201161E 01	0.	6.1039847E-01	7.3393542E-03	9
10	1.3332217E 02	5.4236811E 01	0.	6.1926184E-01	8.0889947E-03	10
11	1.4570637E 02	5.9187787E 01	0.	6.2722306E-01	8.8223926E-03	11
12	1.5794171E 02	6.4062434E 01	0.	6.3445001E-01	9.5412208E-03	12
13	1.7004440E 02	6.8867437E 01	0.	6.4106758E-01	1.0246902E-02	13
14	1.8202770E 02	7.3608255E 01	0.	6.4717120E-01	1.0940052E-02	14
15	1.9390262E 02	7.8289424E 01	0.	6.5283545E-01	1.1623170E-02	15
16	2.0567844E 02	8.2914766E 01	0.	6.5811974E-01	1.2295699E-02	16
17	2.1736308E 02	8.7487547E 01	0.	6.6307215E-01	1.2958802E-02	17
18	2.2896337E 02	9.2010561E 01	0.	6.6773219E-01	1.3613076E-02	18
19	2.4048525E 02	9.6486317E 01	0.	6.7213264E-01	1.4259087E-02	19
20	2.5193395E 02	1.0091691E 02	0.	6.7630109E-01	1.4897296E-02	20
21	2.6331408E 02	1.0530425E 02	0.	6.8026091E-01	1.5528165E-02	21
22	2.7462974E 02	1.0965005E 02	0.	6.8403213E-01	1.6152083E-02	22
23	2.8588462E 02	1.1395581E 02	0.	6.8763201E-01	1.6769375E-02	23
24	2.9708202E 02	1.1822289E 02	0.	6.9107552E-01	1.7380399E-02	24
25	3.0822493E 02	1.2245254E 02	0.	6.9437576E-01	1.7985469E-02	25
26	3.1931607E 02	1.2664586E 02	0.	6.9754426E-01	1.8584765E-02	26
27	5.8429866E 02	1.7206640E 02	0.	7.5597457E-01	3.2167290E-02	27
28	8.3156590E 02	1.7206640E 02	0.	8.0430912E-01	4.3557432E-02	28
29	1.0653106E 03	1.7206640E 02	0.	8.4617506E-01	5.3146771E-02	29
30	1.2885590E 03	1.7206640E 02	0.	8.8190019E-01	6.1233073E-02	30
31	1.5036320E 03	1.7206640E 02	0.	9.1188824E-01	6.8075836E-02	31
32	1.7123493E 03	1.7206640E 02	0.	9.3656770E-01	7.3902041E-02	32
33	1.9161680E 03	1.7206640E 02	0.	9.5637560E-01	7.8912644E-02	33
34	2.1162743E 03	1.7206640E 02	0.	9.7175770E-01	8.3278779E-02	34
35	2.3136458E 03	1.7206640E 02	0.	9.8317667E-01	8.7149665E-02	35
36	2.5090909E 03	1.7206640E 02	0.	9.9112480E-01	9.0659865E-02	36
37	2.7032723E 03	1.7206640E 02	0.	9.9613948E-01	9.3927065E-02	37
38	2.8967174E 03	1.7206640E 02	0.	9.9882056E-01	9.7050072E-02	38
39	3.0896182E 03	1.7206640E 02	0.	9.9984825E-01	1.0010359E-01	39
40	3.2828251E 03	1.7206640E 02	1.7206640E 02	1.0000000E 00	1.0313537E-01	40

	ZETA	I-VIS	C-VIS	U-BAR	Y CO-ORDINATE	
1	4.4721359E-01	0.	0.	1.6495030E-02	1.6162175E-05	1
1	4.4721359E-01	1.0000000E 00	0.	1.6495030E-02	1.6162175E-05	1
2	2.3648221E 01	9.7229913E 00	0.	4.6425125E-01	1.2738525E-03	2
3	3.9430251E 01	1.6193292E 01	0.	5.1007323E-01	2.2949057E-03	3
4	5.4132605E 01	2.2204037E 01	0.	5.3847669E-01	3.2327822E-03	4
5	6.8187280E 01	2.7933066E 01	0.	5.5916477E-01	4.1170667E-03	5
6	8.1787707E 01	3.3460017E 01	0.	5.7546535E-01	4.9621791E-03	6
7	9.5042435E 01	3.8829583E 01	0.	5.8892719E-01	5.7765524E-03	7
8	1.0802037E 02	4.4070137E 01	0.	6.0039924E-01	6.5657003E-03	8
9	1.2076883E 02	4.9201167E 01	0.	6.1039802E-01	7.3334832E-03	9
10	1.3332217E 02	5.4236819E 01	0.	6.1926138E-01	8.0828115E-03	10
11	1.4570637E 02	5.9187795E 01	0.	6.2722260E-01	8.8159074E-03	11
12	1.5794171E 02	6.4062443E 01	0.	6.3444954E-01	9.5344484E-03	12
13	1.7034440E 02	6.8867448E 01	0.	6.4106710E-01	1.0239850E-02	13
14	1.8202770E 02	7.3608267E 01	0.	6.4717072E-01	1.0933234E-02	14
15	1.9390262E 02	7.8289438E 01	0.	6.5283496E-01	1.1615599E-02	15
16	2.0567844E 02	8.2914784E 01	0.	6.5811925E-01	1.2287875E-02	16
17	2.1736308E 02	8.7487566E 01	0.	6.6307167E-01	1.2950731E-02	17
18	2.2896337E 02	9.2010605E 01	0.	6.6773169E-01	1.3604769E-02	18
19	2.4048525E 02	9.6486342E 01	0.	6.7213215E-01	1.4250548E-02	19
20	2.5193395E 02	1.0091694E 02	0.	6.7630059E-01	1.4888533E-02	20
21	2.6331408E 02	1.0530429E 02	0.	6.8026041E-01	1.5519181E-02	21
22	2.7462974E 02	1.0965008E 02	0.	6.8403162E-01	1.6142882E-02	22
23	2.8588462E 02	1.1395584E 02	0.	6.8763149E-01	1.6759966E-02	23
24	2.9708202E 02	1.1822293E 02	0.	6.9107500E-01	1.7370785E-02	24
25	3.0822493E 02	1.2245258E 02	0.	6.9437525E-01	1.7975644E-02	25
26	3.1931607E 02	1.2664591E 02	0.	6.9754375E-01	1.8574736E-02	26
27	5.8429869E 02	1.7206785E 02	0.	7.5597377E-01	3.2153095E-02	27
28	8.3156606E 02	1.7206785E 02	0.	8.0430797E-01	4.3540111E-02	28
29	1.0653109E 03	1.7206785E 02	0.	8.4617372E-01	5.3127001E-02	29
30	1.2885595E 03	1.7206785E 02	0.	8.8130874E-01	6.1211305E-02	30
31	1.5036327E 03	1.7206785E 02	0.	9.1186678E-01	6.8052359E-02	31
32	1.7123502E 03	1.7206785E 02	0.	9.3656629E-01	7.3877192E-02	32
33	1.9161690E 03	1.7206785E 02	0.	9.5637432E-01	7.8886582E-02	33
34	2.1162754E 03	1.7206785E 02	0.	9.7175660E-01	8.3251659E-02	34
35	2.3136470E 03	1.7206785E 02	0.	9.8317579E-01	8.7121601E-02	35
36	2.5090921E 03	1.7206785E 02	0.	9.9112415E-01	9.0630940E-02	36
37	2.7032735E 03	1.7206785E 02	0.	9.9613906E-01	9.3897330E-02	37
38	2.8967185E 03	1.7206785E 02	0.	9.9882035E-01	9.7019554E-02	38
39	3.0898192E 03	1.7206785E 02	0.	9.9984820E-01	1.0007230E-01	39
40	3.2828259E 03	1.7206785E 02	1.7206785E 02	9.9999999E-01	1.0310332E-01	40
41	3.4758030E 03	1.7206785E 02	1.7206785E 02	9.9999999E-01	1.0613101E-01	41

X CO-ORDINATE= 0.29965167E 03   PHI= 0.27112020E 02   ZETA DELTA= 0.32874703E 04

DOCHI LOG SIGMA= 0.   SIGMA OVER MU BAR= 0.43245174E 06   QDOT=-0.32732625E 04BTU PER SQUARE FT-SEC

CF= 0.95476717E-03

A2-6

	PSI	O	N	NO	O2M	O2	N2	NOP	
0	0.	2.9975647E-04	1.9515949E-07	5.9251626E-04	0.	2.3138386E-01	7.6772366E-01	1.2608370E-11	0
1	0.	2.3550175E-04	1.9359629E-07	3.9977027E-04	0.	2.3155127E-01	7.6781325E-01	6.9948354E-13	1
1	1.0000000E-01	2.3550179E-04	1.9359629E-07	3.9977036E-04	0.	2.3155127E-01	7.6781327E-01	6.9948918E-13	1
2	2.0937999E 02	2.0199007E-04	1.2326420E-06	3.8551006E-04	0.	2.3159240E-01	7.6781887E-01	2.1708813E-15	2
3	4.1865999E 02	1.6796820E-04	9.0241518E-07	3.1978303E-04	0.	2.3166148E-01	7.6784986E-01	8.0084157E-17	3
4	6.2793999E 02	1.4581252E-04	6.9354070E-07	2.7682664E-04	0.	2.3170654E-01	7.6787010E-01	4.3096509E-17	4
5	8.3721999E 02	1.2959534E-04	5.5203869E-07	2.4539071E-04	0.	2.3173953E-01	7.6788492E-01	2.9947152E-17	5
6	1.0465000E 03	1.1693309E-04	4.5037220E-07	2.2086460E-04	0.	2.3176527E-01	7.6789646E-01	2.1755044E-17	6
7	1.2557800E 03	1.0669521E-04	3.7470508E-07	2.0105531E-04	0.	2.3178607E-01	7.6790578E-01	1.6316279E-17	7
8	1.4650600E 03	9.8132675E-05	3.1621829E-07	1.8450627E-04	0.	2.3180346E-01	7.6791358E-01	1.2522036E-17	8
9	1.6743400E 03	9.0839548E-05	2.7004722E-07	1.7042767E-04	0.	2.3181826E-01	7.6792020E-01	9.7947328E-18	9
10	1.8836200E 03	8.4590685E-05	2.3329149E-07	1.5838065E-04	0.	2.3183094E-01	7.6792584E-01	7.8027319E-18	10
11	2.0928999E 03	7.9078059E-05	2.0300812E-07	1.4776586E-04	0.	2.3184211E-01	7.6793082E-01	6.2887332E-18	11
12	2.3021800E 03	7.4131320E-05	1.7755984E-07	1.3875200E-04	0.	2.3185213E-01	7.6793529E-01	5.1104264E-18	12
13	2.5114599E 03	6.9766765E-05	1.5653880E-07	1.2986924E-04	0.	2.3186096E-01	7.6793923E-01	4.2050042E-18	13
14	2.7207400E 03	6.5715692E-05	1.3616402E-07	1.2209718E-04	0.	2.3186916E-01	7.6794288E-01	3.4672291E-18	14
15	2.9300199E 03	6.2176327E-05	1.2310390E-07	1.1531697E-04	0.	2.3187632E-01	7.6794604E-01	2.9010629E-18	15
16	3.1393000E 03	5.8939705E-05	1.1010090E-07	1.0912434E-04	0.	2.3188286E-01	7.6794896E-01	2.4421141E-18	16
17	3.3485799E 03	5.5926622E-05	9.8645397E-08	1.0336616E-04	0.	2.3188894E-01	7.6795164E-01	2.0618465E-18	17
18	3.5578600E 03	5.3171459E-05	8.8738153E-08	9.8107687E-05	0.	2.3189450E-01	7.6795412E-01	1.7518888E-18	18
19	3.7671399E 03	5.0623641E-05	8.0055178E-08	9.3250990E-05	0.	2.3189964E-01	7.6795639E-01	1.4954049E-18	19
20	3.9764200E 03	4.8244591E-05	7.2358747E-08	8.8721552E-05	0.	2.3190443E-01	7.6795851E-01	1.2804547E-18	20
21	4.1856999E 03	4.6078020E-05	6.5708693E-08	8.4602128E-05	0.	2.3190880E-01	7.6796045E-01	1.1044746E-18	21
22	4.3949799E 03	4.4017754E-05	5.9685214E-08	8.0689312E-05	0.	2.3191294E-01	7.6796228E-01	9.5331250E-19	22
23	4.6042598E 03	4.2114629E-05	5.4391505E-08	7.7079595E-05	0.	2.3191678E-01	7.6796398E-01	8.2712886E-19	23
24	4.8135399E 03	4.0348352E-05	4.9709862E-08	7.3733658E-05	0.	2.3192033E-01	7.6796554E-01	7.2097263E-19	24
25	5.0228198E 03	3.8692814E-05	4.5521398E-08	7.0601282E-05	0.	2.3192365E-01	7.6796700E-01	6.3051002E-19	25
26	5.2320998E 03	3.7066319E-05	4.1576406E-06	6.7526980E-05	0.	2.3192592E-01	7.6796843E-01	5.4917812E-19	26
27	1.0464100E 04	1.4535546E-05	5.8497513E-09	2.5513537E-05	0.	2.3197186E-01	7.6798809E-01	3.5960110E-20	27
28	1.5696100E 04	4.7013736E-06	5.7036916E-10	7.8422766E-06	0.	2.3199112E-01	7.6799635E-01	1.0688246E-20	28
29	2.0928099E 04	1.1485588E-06	3.3721895E-11	1.7861204E-06	0.	2.3199790E-01	7.6799916E-01	1.0005232E-20	29
30	2.6160100E 04	2.0497344E-07	1.2064347E-12	2.9051209E-07	0.	2.3199964E-01	7.6799986E-01	9.9973179E-21	30
31	3.1392100E 04	2.6268777E-08	2.7958276E-14	3.3095245E-08	0.	2.3199996E-01	7.6799998E-01	9.9972806E-21	31
32	3.6624100E 04	2.4508886E-09	3.3776434E-15	2.6881064E-09	0.	2.3199999E-01	7.6799998E-01	9.9972807E-21	32
33	4.1856099E 04	1.8413946E-10	9.7879827E-16	1.7095098E-10	0.	2.3200000E-01	7.6799999E-01	9.9972807E-21	33
34	4.7088099E 04	1.1786217E-11	9.7694534E-16	9.1564450E-12	0.	2.3200001E-01	7.6799999E-01	9.9972808E-21	34
35	5.2320099E 04	8.4364696E-13	9.7935072E-16	5.4934875E-13	0.	2.3200000E-01	7.6799998E-01	9.9972806E-21	35
36	5.7552099E 04	8.5768840E-14	9.8128551E-16	4.7314995E-14	0.	2.3199999E-01	7.6799998E-01	9.9972804E-21	36
37	6.2784100E 04	1.6988817E-14	9.8258761E-16	7.9795049E-15	0.	2.3200000E-01	7.6799998E-01	9.9972806E-21	37
38	6.8016099E 04	6.9255357E-15	9.8332334E-16	2.7778194E-15	0.	2.3200000E-01	7.6799998E-01	9.9972806E-21	38
39	7.3248100E 04	5.0245564E-15	9.8360336E-16	1.8453383E-15	0.	2.3200000E-01	7.6799999E-01	9.9972807E-21	39
40	7.8480099E 04	4.7716050E-15	9.8365459E-16	1.7233097E-15	0.	2.3200000E-01	7.6800001E-01	9.9972817E-21	40
41	0.3712099E 04	1.0011850E-15	9.9999484E-16	5.5145031E-19	0.	2.3200000E-01	7.6799999E-01	9.9999990E-21	41

CSI =-0.

	PSI	G	TEMP	RHO	W		ELEC. CON.	ELEC. DENS.
0	0.	9.2218490E-01	2.5142028E 00	3.9774039E-01	2.8836251E 01	-0.	-0.	0
1	1.0000000E-01	9.2218490E-01	2.5136265E 00	3.9783158E-01	2.8836251E 01	-0.	-0.	1
1	1.0000000E-01	9.3428999E-01	2.5457046E 00	3.9281855E-01	2.8836251E 01	-0.	-0.	1
2	2.9040000E 00	9.3971000E-01	2.5439179E 00	3.9309444E-01	2.8836251E 01	-0.	-0.	2
3	5.7079999E 00	9.4238000E-01	2.5348440E 00	3.9450160E-01	2.8836251E 01	-0.	-0.	3
4	8.5119998E 00	9.4444999E-01	2.5241791E 00	3.9616840E-01	2.8836251E 01	-0.	-0.	4
5	1.1316000E 01	9.4619000E-01	2.5126369E 00	3.9798826E-01	2.8836251E 01	-0.	-0.	5
6	1.4120000E 01	9.4771999E-01	2.5005364E 00	3.9991419E-01	2.8836251E 01	-0.	-0.	6
7	1.6923999E 01	9.4911999E-01	2.4880886E 00	4.0191495E-01	2.8836251E 01	-0.	-0.	7
8	1.9727999E 01	9.5039999E-01	2.4753208E 00	4.0398804E-01	2.8836251E 01	-0.	-0.	8
9	2.2531999E 01	9.5159000E-01	2.4623109E 00	4.0612256E-01	2.8836251E 01	-0.	-0.	9
10	2.5335999E 01	9.5271000E-01	2.4491127E 00	4.0831113E-01	2.8836251E 01	-0.	-0.	10
11	2.8139999E 01	9.5375999E-01	2.4357260E 00	4.1055520E-01	2.8836251E 01	-0.	-0.	11
12	3.0943999E 01	9.5476998E-01	2.4222303E 00	4.1284266E-01	2.8836251E 01	-0.	-0.	12
13	3.3747998E 01	9.5572999E-01	2.4085990E 00	4.1517911E-01	2.8836251E 01	-0.	-0.	13
14	3.6551998E 01	9.5666000E-01	2.3948848E 00	4.1755661E-01	2.8836251E 01	-0.	-0.	14
15	3.9355998E 01	9.5754999E-01	2.3810616E 00	4.1998073E-01	2.8836251E 01	-0.	-0.	15
16	4.2159998E 01	9.5839999E-01	2.3671294E 00	4.2245261E-01	2.8836251E 01	-0.	-0.	16
17	4.4963998E 01	9.5922999E-01	2.3531403E 00	4.2496403E-01	2.8836251E 01	-0.	-0.	17
18	4.7767998E 01	9.6003999E-01	2.3390958E 00	4.2751563E-01	2.8836251E 01	-0.	-0.	18
19	5.0571998E 01	9.6082000E-01	2.3249673E 00	4.3011357E-01	2.8836251E 01	-0.	-0.	19
20	5.3375998E 01	9.6157999E-01	2.3107835E 00	4.3275366E-01	2.8836251E 01	-0.	-0.	20
21	5.6179997E 01	9.6231999E-01	2.2965427E 00	4.3543714E-01	2.8836251E 01	-0.	-0.	21
22	1.1178400E 03	9.7686000E-01	1.9434477E 00	5.1454948E-01	2.8836251E 01	-0.	-0.	22
23	2.1795000E 03	9.8074000E-01	1.8224283E 00	5.4871843E-01	2.8836251E 01	-0.	-0.	23
24	3.2411600E 03	9.8384999E-01	1.7208819E 00	5.8109739E-01	2.8836251E 01	-0.	-0.	24
25	4.3028200E 03	9.8659999E-01	1.6240180E 00	6.1575672E-01	2.8836251E 01	-0.	-0.	25
26	5.3644800E 03	9.8902999E-01	1.5332330E 00	6.5221657E-01	2.8836251E 01	-0.	-0.	26
27	6.4261400E 03	9.9115000E-01	1.4493702E 00	6.8995486E-01	2.8836251E 01	-0.	-0.	27
28	7.4877999E 03	9.9298000E-01	1.3729775E 00	7.2834405E-01	2.8836251E 01	-0.	-0.	28
29	8.5494598E 03	9.9454999E-01	1.3044026E 00	7.6663446E-01	2.8836251E 01	-0.	-0.	29
30	9.6111197E 03	9.9586999E-01	1.2437585E 00	8.0401460E-01	2.8836251E 01	-0.	-0.	30
31	1.0672780E 04	9.9696999E-01	1.1910595E 00	8.3958859E-01	2.8836251E 01	-0.	-0.	31
32	1.1734440E 04	9.9786999E-01	1.1461600E 00	8.7247851E-01	2.8836251E 01	-0.	-0.	32
33	1.2796099E 04	9.9856999E-01	1.1047392E 00	9.0192536E-01	2.8836251E 01	-0.	-0.	33
34	1.3857759E 04	9.9911000E-01	1.0744699E 00	9.2723955E-01	2.8836251E 01	-0.	-0.	34
35	1.4919419E 04	9.9948999E-01	1.0548070E 00	9.4804071E-01	2.8836251E 01	-0.	-0.	35
36	1.5981079E 04	9.9974999E-01	1.0372031E 00	9.6413133E-01	2.8836251E 01	-0.	-0.	36
37	1.7042739E 04	9.9990000E-01	1.0249186E 00	9.7568721E-01	2.8836251E 01	-0.	-0.	37
38	1.8104399E 04	9.9997000E-01	1.0171538E 00	9.8313546E-01	2.8836251E 01	-0.	-0.	38
39	1.9166059E 04	1.0000000E 00	1.0130177E 00	9.8714955E-01	2.8836251E 01	-0.	-0.	39
40	2.0227719E 04	1.0000000E 00	1.0114159E 00	9.8871298E-01	2.8836251E 01	-0.	-0.	40

LE= 40LS= 40

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        TURBULENT  TRANSPORT  ANALYSIS
             ORIGINATOR -   H. ROSENBAUM
             PROGRAMMER -   B. BELLON

 CHECK RUN OF AIR   INPUT      6/23/65  SUBLAYER HYPOTHESIS

COARSE PSI STEP=   1061.66   INITIAL CSI=-0.         FINAL CSI= 0.35E 06      CSI STEP TOLERANCE=   0.20000E 04

INITIAL PHI=      24.25400   ZETA DELTA=   1012.480  HE=   0.3577900E 07      CSI STEP=      0.1000E 06

FINE PSI STEP=       0.100   WALL TEMP TOL= 0.05000  D-RAP TOL= 1.00E-03      PSI ONE=             0.100
DELTA=                 -0.

PRANDTL NUMBER=  1.00        SCHMIDT NUMBER= 1.00    TE=       121.63         UE=     2138.85
RHO E=  0.4223000E-03        MU E=  0.1758700E-06    TR=       300.00         DO CHI LOG SIG= -0.

MAX NO. OF CSI CUTBACKS=    5     MAX NO. OF CSI STEPS BEFORE DOUBLING=  500
NO OF SPECIES COARSE PSI POINTS=   20     NO. OF COARSE G POINTS=   20     NO. OF FINE PSI POINTS=   20

NO. OF SPECIES=    7     MAX NO. OF WALL TEMP ITERATIONS=    5     PRINT CYCLE NUMBER=    1

THE WALL TEMPERATURE FUNCTION VERSVS X IS
             305.8100+     -0.     X FOR X LESS THAN     0.2400000E 08
             305.8100+     -0.     X FOR X GREATER THAN  0.2400000E 08

THE FOLLOWING ARE MOLECULAR WEIGHTS FOR THE SAME SPECIES
 1.6000000E 01  1.4000000E 01  3.0000000E 01  3.2000000E 01  3.2000000E 01  2.8000000E 01  3.0000000E 01
```

	ZETA	I-VIS	C-VIS	U-BAR	Y CO-ORDINATE	
1	4.4721359E-01	0.	0.	1.8438755E-02	1.6965187E-05	1
1	4.4721359E-01	1.0000000E 00	0.	1.8438756E-02	1.6965187E-05	1
2	2.4099792E 00	9.9999197E-01	0.	9.9364195E-02	9.2338420E-05	2
3	3.3767571E 00	9.9997790E-01	0.	1.3930721E-01	1.2946160E-04	3
4	4.1260150E 00	9.9995978E-01	0.	1.7011689E-01	1.5798493E-04	4
5	4.7573101E 00	9.9993834E-01	0.	1.9614538E-01	1.8197612E-04	5
6	5.3141320E 00	9.9991407E-01	0.	2.1910332E-01	2.0303775E-04	6
7	5.8179033E 00	9.9988725E-01	0.	2.3987397E-01	2.2199946E-04	7
8	6.2814010E 00	9.9985811E-01	0.	2.5898412E-01	2.3935710E-04	8
9	6.7129724E 00	9.9982680E-01	0.	2.7677795E-01	2.5543520E-04	9
10	7.1184267E 00	9.9979349E-01	0.	2.9349495E-01	2.7046012E-04	10
11	7.5019996E 00	9.9975828E-01	0.	3.0930979E-01	2.8459725E-04	11
12	7.8668925E 00	9.9972128E-01	0.	3.2435443E-01	2.9797189E-04	12
13	8.2155948E 00	9.9968255E-01	0.	3.3873154E-01	3.1068172E-04	13
14	8.5500876E 00	9.9964217E-01	0.	3.5252278E-01	3.2280461E-04	14
15	8.8719782E 00	9.9960023E-01	0.	3.6579443E-01	3.3440388E-04	15
16	9.1825920E 00	9.9955676E-01	0.	3.7860114E-01	3.4553175E-04	16
17	9.4830374E 00	9.9951180E-01	0.	3.9098859E-01	3.5623204E-04	17
18	9.7742517E 00	9.9946543E-01	0.	4.0299545E-01	3.6654197E-04	18
19	1.0057037E 01	9.9941767E-01	0.	4.1465478E-01	3.7649337E-04	19
20	1.0332086E 01	9.9936858E-01	0.	4.2599512E-01	3.8611376E-04	20
21	1.0600000E 01	9.9931818E-01	0.	4.3704130E-01	3.9542714E-04	21
22	8.6340808E 01	3.4590590E 01	0.	6.4870430E-01	2.8184524E-03	22
23	1.5077327E 02	5.3082776E 01	0.	7.0539950E-01	4.6492226E-03	23
24	2.1093411E 02	5.3082776E 01	0.	7.4944825E-01	6.2575936E-03	24
25	2.6782740E 02	5.3082776E 01	0.	7.889[illegible]56E-01	7.6934377E-03	25
26	3.2208967E 02	5.3082776E 01	0.	8.2402209E-01	8.9860556E-03	26
27	3.7421403E 02	5.3082776E 01	0.	8.5506474E-01	1.0159059E-02	27
28	4.2459030E 02	5.3082776E 01	0.	8.8230258E-01	1.1231812E-02	28
29	4.7353255E 02	5.3082776E 01	0.	9.0599306E-01	1.2220495E-02	29
30	5.2129820E 02	5.3082776E 01	0.	9.2638130E-01	1.3138839E-02	30
31	5.6810154E 02	5.3082775E 01	0.	9.4370182E-01	1.3998657E-02	31
32	6.1412321E 02	5.3082776E 01	0.	9.5818156E-01	1.4810225E-02	32
33	6.5951713E 02	5.3082776E 01	0.	9.7004398E-01	1.5582529E-02	33
34	7.0441542E 02	5.3082775E 01	0.	9.7951332E-01	1.6323469E-02	34
35	7.4893181E 02	5.3082776E 01	0.	9.8681927E-01	1.7039992E-02	35
36	7.9316404E 02	5.3082776E 01	0.	9.9220172E-01	1.7738169E-02	36
37	8.3719527E 02	5.3082776E 01	0.	9.9591581E-01	1.8423245E-02	37
38	8.8109478E 02	5.3082776E 01	0.	9.9823685E-01	1.9099629E-02	38
39	9.2491798E 02	5.3082776E 01	0.	9.9946530E-01	1.9770904E-02	39
40	9.6870594E 02	5.3082776E 01	0.	9.9993159E-01	2.0437742E-02	40

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	PSI	O	N	NO	O2M	O2	N2	NO+	
0	0.	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	0
1	0.	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	1
1	1.0000000E-01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	1
2	2.9040000E 00	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	2
3	5.7079999E 00	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	3
4	8.5119998E 00	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	4
5	1.1316000E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	5
6	1.4120000E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	6
7	1.6923999E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	7
8	1.9727999E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	8
9	2.2531999E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	9
10	2.5335999E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	10
11	2.8139999E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	11
12	3.0943999E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	12
13	3.3747998E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	13
14	3.6551998E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	14
15	3.9355998E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	15
16	4.2159998E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	16
17	4.4963998E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	17
18	4.7767998E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	18
19	5.0571998E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	19
20	5.3375998E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	20
21	5.6179997E 01	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	21
22	1.1178400E 03	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	22
23	2.1795000E 03	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	23
24	3.2411600E 03	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	24
25	4.3028200E 03	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	25
26	5.3644800E 03	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	26
27	6.4261400E 03	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	27
28	7.4877999E 03	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	28
29	8.5494598E 03	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	29
30	9.6111197E 03	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	30
31	1.0672780E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	31
32	1.1734440E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	32
33	1.2796099E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	33
34	1.3857759E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	34
35	1.4919419E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	35
36	1.5981079E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	36
37	1.7042739E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	37
38	1.8104399E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	38
39	1.9166059E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	39
40	2.0227719E 04	-0.	-0.	-0.	-0.	2.3200000E-01	7.6799999E-01	-0.	40

	PSI	O	H	NO	O2M	O2	N2		NOR
0	0.	0.	0.	0.	0.	2.3200043E-01	7.6800138E-01	0.	0
1	0.	0.	0.	0.	0.	2.3200043E-01	7.6800138E-01	0.	1
1	1.0000000E-01	0.	0.	0.	0.	2.3200043E-01	7.6800139E-01	0.	1
2	2.9040000E 00	0.	0.	0.	0.	2.3200044E-01	7.6800141E-01	0.	2
3	5.7079999E 00	0.	0.	0.	0.	2.3200044E-01	7.6800144E-01	0.	3
4	8.5119998E 00	0.	0.	0.	0.	2.3200044E-01	7.6800144E-01	0.	4
5	1.1316000E 01	0.	0.	0.	0.	2.3200044E-01	7.6800144E-01	0.	5
6	1.4120000E 01	0.	0.	0.	0.	2.3200044E-01	7.6800144E-01	0.	6
7	1.6923999E 01	0.	0.	0.	0.	2.3200045E-01	7.6800144E-01	0.	7
8	1.9727999E 01	0.	0.	0.	0.	2.3200045E-01	7.6800145E-01	0.	8
9	2.2531999E 01	0.	0.	0.	0.	2.3200045E-01	7.6800144E-01	0.	9
10	2.5335999E 01	0.	0.	0.	0.	2.3200044E-01	7.6800143E-01	0.	10
11	2.8139999E 01	0.	0.	0.	0.	2.3200043E-01	7.6800140E-01	0.	11
12	3.0943999E 01	0.	0.	0.	0.	2.3200042E-01	7.6800137E-01	0.	12
13	3.3747998E 01	0.	0.	0.	0.	2.3200040E-01	7.6800132E-01	0.	13
14	3.6551998E 01	0.	0.	0.	0.	2.3200039E-01	7.6800127E-01	0.	14
15	3.9355998E 01	0.	0.	0.	0.	2.3200037E-01	7.6800122E-01	0.	15
16	4.2159998E 01	0.	0.	0.	0.	2.3200036E-01	7.6800117E-01	0.	16
17	4.4963998E 01	0.	0.	0.	0.	2.3200034E-01	7.6800111E-01	0.	17
18	4.7767998E 01	0.	0.	0.	0.	2.3200032E-01	7.6800104E-01	0.	18
19	5.0571998E 01	0.	0.	0.	0.	2.3200030E-01	7.6800097E-01	0.	19
20	5.3375998E 01	0.	0.	0.	0.	2.3200028E-01	7.6800091E-01	0.	20
21	5.6179997E 01	0.	0.	0.	0.	2.3200026E-01	7.6800084E-01	0.	21
22	1.1178400E 03	0.	0.	0.	0.	2.3200008E-01	7.6800026E-01	0.	22
23	2.1795000E 03	0.	0.	0.	0.	2.3200004E-01	7.6800014E-01	0.	23
24	3.2411600E 03	0.	0.	0.	0.	2.3200002E-01	7.6800008E-01	0.	24
25	4.3028200E 03	0.	0.	0.	0.	2.3200001E-01	7.6800004E-01	0.	25
26	5.3644800E 03	0.	0.	0.	0.	2.3200000E-01	7.6800001E-01	0.	26
27	6.4261400E 03	0.	0.	0.	0.	2.3200000E-01	7.6799999E-01	0.	27
28	7.4877999E 03	0.	0.	0.	0.	2.3200000E-01	7.6799998E-01	0.	28
29	8.5494598E 03	0.	0.	0.	0.	2.3199999E-01	7.6799998E-01	0.	29
30	9.6111197E 03	0.	0.	0.	0.	2.3199999E-01	7.6799998E-01	0.	30
31	1.0672780E 04	0.	0.	0.	0.	2.3199999E-01	7.6799996E-01	0.	31
32	1.1734440E 04	0.	0.	0.	0.	2.3199999E-01	7.6799996E-01	0.	32
33	1.2796099E 04	0.	0.	0.	0.	2.3199999E-01	7.6799996E-01	0.	33
34	1.3857759E 04	0.	0.	0.	0.	2.3199999E-01	7.6799996E-01	0.	34
35	1.4919419E 04	0.	0.	0.	0.	2.3199998E-01	7.6799996E-01	0.	35
36	1.5981079E 04	0.	0.	0.	0.	2.3199998E-01	7.6799995E-01	0.	36
37	1.7042739E 04	0.	0.	0.	0.	2.3199998E-01	7.6799995E-01	0.	37
38	1.8104399E 04	0.	0.	0.	0.	2.3199999E-01	7.6799996E-01	0.	38
39	1.9166059E 04	0.	0.	0.	0.	2.3199999E-01	7.6799996E-01	0.	39
40	2.0227719E 04	0.	0.	0.	0.	2.3199998E-01	7.6799996E-01	0.	40
41	2.1289379E 04	0.	0.	0.	0.	2.3199998E-01	7.6799996E-01	0.	41
42	2.2351038E 04	0.	0.	0.	0.	2.3199999E-01	7.6799996E-01	0.	42
43	2.3412699E 04	0.	0.	0.	0.	2.3199999E-01	7.6799996E-01	0.	43

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CSI = 0.09999999E 06

	PSI	G	TEMP	RHO	W		ELEC. CON.	ELEC. DENS.
0	0.	9.2218654E-01	2.5142024E 00	3.9773973E-01	2.8836199E 01	0.	0.	0
1	1.0000000E-01	9.2452204E-01	2.5198242E 00	3.9685236E-01	2.8836199E 01	0.	0.	1
1	1.0000000E-01	9.2452205E-01	2.5198242E 00	3.9685236E-01	2.8836198E 01	0.	0.	1
2	2.9040000E 00	9.3296521E-01	2.5262659E 00	3.9584042E-01	2.8836198E 01	0.	0.	2
3	5.7079999E 00	9.3794743E-01	2.5235345E 00	3.9626885E-01	2.8836197E 01	0.	0.	
4	8.5119996E 00	9.4182247E-01	2.5176691E 00	3.9716049E-01	2.8836197E 01	0.	0.	4
5	1.1316000E 01	9.4510299E-01	2.5106274E 00	3.9830606E-01	2.8836197E 01	0.	0.	5
6	1.4120000E 01	9.4799904E-01	2.5023648E 00	3.9962123E-01	2.8836197E 01	0.	0.	6
7	1.6923999E 01	9.5062006E-01	2.4933743E 00	4.0106216E-01	2.8836197E 01	0.	0.	7
8	1.9727999E 01	9.5303390E-01	2.4838298E 00	4.0260330E-01	2.8836196E 01	0.	0.	8
9	2.2531999E 01	9.5528218E-01	2.4738460E 00	4.0422812E-01	2.8836197E 01	0.	0.	9
10	2.5335999E 01	9.5739571E-01	2.4635039E 00	4.0592512E-01	2.8836197E 01	0.	0.	10
11	2.8139999E 01	9.5939664E-01	2.4528604E 00	4.0768653E-01	2.8836198E 01	0.	0.	11
12	3.0943999E 01	9.6130170E-01	2.4419614E 00	4.0950614E-01	2.8836200E 01	0.	0.	12
13	3.3747998E 01	9.6312392E-01	2.4308403E 00	4.1137966E-01	2.8836201E 01	0.	0.	13
14	3.6551998E 01	9.6487370E-01	2.4195249E 00	4.1330359E-01	2.8836203E 01	0.	0.	14
15	3.9355998E 01	9.6655947E-01	2.4080378E 00	4.1527520E-01	2.8836205E 01	0.	0.	15
16	4.2159998E 01	9.6818818E-01	2.3963973E 00	4.1729244E-01	2.8836207E 01	0.	0.	16
17	4.4963998E 01	9.6976566E-01	2.3846179E 00	4.1935379E-01	2.8836209E 01	0.	0.	17
18	4.7767998E 01	9.7129686E-01	2.3727139E 00	4.2145774E-01	2.8836212E 01	0.	0.	18
19	5.0571998E 01	9.7278601E-01	2.3606956E 00	4.2360342E-01	2.8836215E 01	0.	0.	19
20	5.3375998E 01	9.7423673E-01	2.3485731E 00	4.2578995E-01	2.8836217E 01	0.	0.	20
21	5.6179997E 01	9.7565222E-01	2.3363548E 00	4.2801671E-01	2.8836220E 01	0.	0.	21
22	1.1178400E 03	9.7953981E-01	1.9602854E 00	5.1012962E-01	2.8836241E 01	0.	0.	22
23	2.1795000E 03	9.8199177E-01	1.8337076E 00	5.4386017E-01	2.8836246E 01	0.	0.	23
24	3.2411600E 03	9.8424716E-01	1.7425884E 00	5.7385892E-01	2.8836248E 01	0.	0.	24
25	4.3028200E 03	9.8648945E-01	1.6509625E 00	6.0570726E-01	2.8836250E 01	0.	0.	25
26	5.3644800E 03	9.8860415E-01	1.5645659E 00	6.3915492E-01	2.8836251E 01	0.	0.	26
27	6.4261400E 03	9.9053541E-01	1.4841902E 00	6.7376812E-01	2.8836251E 01	0.	0.	27
28	7.4877999E 03	9.9226022E-01	1.4100974E 00	7.0917089E-01	2.8836252E 01	0.	0.	28
29	8.5494598E 03	9.9377373E-01	1.3426202E 00	7.4481229E-01	2.8836252E 01	0.	0.	29
30	9.6111197E 03	9.9507973E-01	1.2819152E 00	7.8008283E-01	2.8836252E 01	0.	0.	30
31	1.0672780E 04	9.9618853E-01	1.2280331E 00	8.1431031E-01	2.8836252E 01	0.	0.	31
32	1.1734440E 04	9.9711270E-01	1.1809236E 00	8.4679488E-01	2.8836252E 01	0.	0.	32
33	1.2796099E 04	9.9786562E-01	1.1404432E 00	8.7685215E-01	2.8836252E 01	0.	0.	33
34	1.3857759E 04	9.9846452E-01	1.1063705E 00	9.0385635E-01	2.8836252E 01	0.	0.	34
35	1.4919419E 04	9.9892614E-01	1.0783993E 00	9.2730035E-01	2.8836252E 01	0.	0.	35
36	1.5981079E 04	9.9927033E-01	1.0561500E 00	9.4683528E-01	2.8836253E 01	0.	0.	36
37	1.7042739E 04	9.9951620E-01	1.0391600E 00	9.6231580E-01	2.8836253E 01	0.	0.	37
38	1.8104399E 04	9.9968432E-01	1.0268868E 00	9.7381530E-01	2.8836252E 01	0.	0.	38
39	1.9166059E 04	9.9979506E-01	1.0197117E 00	9.8163205E-01	2.8836252E 01	0.	0.	39
40	2.0227719E 04	9.9986485E-01	1.0139066E 00	9.8628415E-01	2.8836252E 01	0.	0.	40
41	2.1289379E 04	9.9990778E-01	1.0116561E 00	9.8847826E-01	2.8836252E 01	0.	0.	41
42	2.2351038E 04	9.9993238E-01	1.0110352E 00	9.8908529E-01	2.8836257E 01	0.		42
43	2.3412699E 04	9.9994358E-01	1.0112293E 00	9.8909110E-01	2.8836252E 01	0.		43

LE= 43LS= 43

	ZETA	1-VIS	C-VIS	U-BAR	Y CO-ORDINATE	
1	4.4721359E-01	0.	0.	1.8314410E-02	1.7468362E-05	1
1	4.4721359E-01	1.0000000E 00	0.	1.8314411E-02	1.7468362E-05	1
2	2.4099792E 00	9.9999261E-01	0.	9.8694118E-02	9.4318581E-05	2
3	3.3787571E 00	9.9997966E-01	0.	1.3836777E-01	1.3227805E-04	3
4	4.1260150E 00	9.9996300E-01	0.	1.6896968E-01	1.6150905E-04	4
5	4.7573101E 00	9.9994327E-01	0.	1.9482265E-01	1.8614063E-04	5
6	5.3141320E 00	9.9992095E-01	0.	2.1762577E-01	2.0779946E-04	6
7	5.8179033E 00	9.9989628E-01	0.	2.3825634E-01	2.2732733E-04	7
8	6.2814010E 00	9.9986945E-01	0.	2.5723763E-01	2.4522740E-04	8
9	6.7129724E 00	9.9984065E-01	0.	2.7491145E-01	2.6182909E-04	9
10	7.1184267E 00	9.9981002E-01	0.	2.9151573E-01	2.7736216E-04	10
11	7.5019996E 00	9.9977762E-01	0.	3.0722391E-01	2.9199450E-04	11
12	7.8668925E 00	9.9974358E-01	0.	3.2216710E-01	3.0585325E-04	12
13	8.2155948E 00	9.9970795E-01	0.	3.3644725E-01	3.1903749E-04	13
14	8.5500876E 00	9.9967080E-01	0.	3.5014549E-01	3.3162624E-04	14
15	8.8719782E 00	9.9963220E-01	0.	3.6332764E-01	3.4368376E-04	15
16	9.1825920E 00	9.9959221E-01	0.	3.7604798E-01	3.5526312E-04	16
17	9.4830374E 00	9.9955087E-01	0.	3.8835190E-01	3.6640881E-04	17
18	9.7742517E 00	9.9950820E-01	0.	4.0027779E-01	3.7715854E-04	18
19	1.0057037E 01	9.9946427E-01	0.	4.1185849E-01	3.8754464E-04	19
20	1.0332086E 01	9.9941911E-01	0.	4.2312236E-01	3.9759506E-04	20
21	1.0600000E 01	9.9937274E-01	0.	4.3409405E-01	4.0733418E-04	21
22	8.6340808E 01	3.4665857E 01	0.	6.4432967E-01	2.9324432E-03	22
23	1.5077980E 02	5.6802464E 01	0.	7.0003099E-01	4.8319386E-03	23
24	2.1109464E 02	5.6802464E 01	0.	7.4137923E-01	6.5079824E-03	24
25	2.6828266E 02	5.6802464E 01	0.	7.7879448E-01	8.0138276E-03	25
26	3.2291566E 02	5.6802464E 01	0.	8.1245372E-01	9.3769292E-03	26
27	3.7544360E 02	5.6802464E 01	0.	8.4256133E-01	1.0619536E-02	27
28	4.2622668E 02	5.6802464E 01	0.	8.6932656E-01	1.1760001E-02	28
29	4.7555804E 02	5.6802464E 01	0.	8.9295411E-01	1.2813673E-02	29
30	5.2367969E 02	5.6802464E 01	0.	9.1364077E-01	1.3743649E-02	30
31	5.7079517E 02	5.6802464E 01	0.	9.3157535E-01	1.4711237E-02	31
32	6.1707594E 02	5.6802464E 01	0.	9.4694002E-01	1.55763[illegible]E-02	32
33	6.6266971E 02	5.6802464E 01	0.	9.5991261E-01	1.63975[illegible]-02	33
34	7.0770386E 02	5.6802464E 01	0.	9.7066931E-01	1.71826[illegible]E-02	34
35	7.5228916E 02	5.6802464E 01	0.	9.7930752E-01	1.7938473E-02	35
36	7.9652199E 02	5.6802464E 01	0.	9.8624903E-01	1.8671081E-02	36
37	8.4048623E 02	5.6802464E 01	0.	9.9144324E-01	1.9385855E-02	37
38	8.8425416E 02	5.6802464E 01	0.	9.9517051E-01	2.0087500E-02	38
39	9.2786708E 02	5.6802464E 01	0.	9.9764551E-01	2.0780058E-02	39
40	9.7143551E 02	5.6802464E 01	0.	9.9910070E-01	2.1466887E-02	40
41	1.0149387E 03	5.6802464E 01	0.	9.9978955E-01	2.2150622E-02	41
42	1.0584242E 03	5.6802464E 01	0.	9.9998950E 01	2.2833110E-02	42
43	1.1019058E 03	5.6802464E 01	5.6802464E 01	9.9999990E-01	2.3515324E-02	43

X CO-ORDINATE= 0.11509554E 07 PHI= 0.24416671E 02 ZETA DELTA= 0.10834698E 04

DDCHI LOG SIGMA= 0.31316543E-07 SIGMA OVER MU BAR= 0.17420866E 07 QDOT=-0.24081224E-00BTU PER SQUARE FT-SEC

CF= 0.90948302E-03